THE

GEOLOGICAL STORY

BRIEFLY TOLD.

An Introduction to Geology

FOR

THE GENERAL READER AND FOR BEGINNERS
IN THE SCIENCE.

BY

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WITH NUMEROUS ILLUSTRATIONS.

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PREFATORY SUGGESTIONS.

GEOLOGY is eminently an out-door science; for strata, rivers, oceans, mountains, valleys, volcanoes, cannot be taken into a recitation-room. Sketches and sections serve a good purpose in illustrating the objects of which the science treats, but they do not set aside the necessity of seeing the objects themselves. The reader who has any interest in the subject should therefore go, for aid in his study, to the quarries, bluffs, or ledges of rocks in his vicinity, and all places that illustrate geological operations. At each locality accessible to him he should observe the kinds of rocks that there occur; whether they consist of layers or not; and their positions, whether the layers are horizontal, — the positon they had when made; or whether inclined, — a slope in the beds being evidence of a subterranean movement like that which takes place in mountain-making.

Geology teaches that much the larger part of the rocks that consist of layers were made through the action of water; and if such rocks are accessible, it is well, after learning the lessons of the book, to look among them for evidence of this mode of origin, either in the structure of the layers, in the nature of the material, in markings within the beds, or in the presence of relics of aquatic life, such as

shells, bones, etc. If some of the layers in a bluff consist of sandstone, others are pebbly, others clayey, and one or more are of limestone, the kinds of changes in the waters that took place to produce so varied results should be made a point for investigation.

If an excavation for a cellar is opened near an accustomed walk, it is best to look at the sections of the earth or sands thus made; for these sands are very often in layers, and, in that case, they bear evidence that there even the loose material of the surface had been arranged by water, either that of the ocean or that of a river or lake.

When the layers contain fossils, a collection should be made for study; for they show what living species populated the waters or land when the rocks were forming; and in the height of a single bluff there may be records thus made of several successive populations different from one another.

If a beach or a cliff along the ocean is accessible, the action of the waves in their successive plunges may be watched to great advantage; for they are thus grinding up the stones and sands of the beach, and eroding and undermining the cliff. While viewing such work on a seashore, it will be a good time to consider that this battering goes on almost incessantly through the year, and year after year, and has so gone on along coasts and about reefs for indefinite ages. The cliff and the rocky ledges in the surf at its base should be closely examined, that the amount and kind of wear may be appreciated; and the action of the water over the beach should be studied in order to understand why, after so much grinding, coarse sands and often pebbles are still left.

If there are sand-flats exposed off the shores at low tide, there is a chance to discover by what currents or movements of the water they were formed, and whence came the sands that compose them, which should be taken advantage of; for they are identical in kind and mode of origin, although not in extent, with the sand-flats of ancient time out of which sandstones have been made; the only possible difference being that in the earlier ages the waters were everywhere salt, and rivers gave little aid. And if the sandy surface is left rippled as the tide goes out, note this, for ancient sandstones often contain such ripple-marks over their layers; or if the muddy portions are marked with the tracks of Mollusks, note this also, for in many rocks just such tracks occur.

If coral reefs or shell rocks are forming along the shores, — as in the West Indies, — these formations should receive special study; for many of the old limestones of the world were made in the same way.

If a heavy rain has gullied a side-hill or proved disastrous to roads, here is a fruitful field for study; for the gullies are miniature valleys, and they illustrate how most great valleys were excavated, — the latter being as truly the work of running water as the former. The same gullied slope may exemplify also the formation of precipices and waterfalls, of crested ridges, table-topped summits, and groups or ranges of mountain-peaks.

These are some of the points of easy observation. Many others will occur to the reader after a perusal of the following pages.

A few labelled specimens of minerals and rocks are absolutely indispensable for even a partial understanding of the subject, and the

student should buy or beg them, if not able to do the better thing of collecting them.

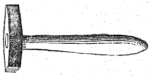
Of MINERALS: 1, crystallized quartz; 2, two or three quartz pebbles of different colors; 3, the variety of quartz called hornstone or flint; 4, common feldspar; 5, mica; 6, black hornblende; 7, a black or greenish-black crystal of augite, and better if in a volcanic rock; 8, garnet; 9, tourmaline; 10, calcite (carbonate of lime), a cleavable specimen; 11, dolomite, or magnesian carbonate of lime; 12, gypsum, or sulphate of lime; 13, pyrite (sulphid of iron); 14, magnetite, or magnetic iron ore; 15, hematite, or specular iron ore; 16, limonite, the common iron ore often called "brown hematite"; 17, siderite, or spathic iron ore; 18, chalcopyrite, or yellow copper ore; 19, galenite, or lead ore (sulphide of lead); 20, graphite.

Of ROCKS: 1, 2, 3, common compact limestone of three different colors, one, at least, of the specimens with a fossil in it; 4, chalk, a variety of compact limestone; 5, 6, white and clouded granular or crystalline limestone, of which the ordinary architectural marble is an example; 7, 8, red and gray sandstone; 9, conglomerate, called also pudding-stone; 10, shale, such as the slaty rock of the coal-formation, and other shales of the Silurian and Devonian; 11, slate, or argillyte, that is, common roofing-slate, or writing-slate; 12, 13, coarse and fine-grained grayish or reddish granite (to be obtained, like marbles and sandstones, in many stone-yards); 14, red or gray syenyte, of which the Scotch "granite" and Quincy "granite" are good examples; 15, gneiss, a piece that has the mica distinctly in planes, and hence is banded on a surface of transverse fracture; 16, mica schist; 17, trap, an igneous rock; 18, trachyte, an igneous rock; 19, lava, a cellular volcanic rock; 20, a piece of diatom or infusorial earth.

The above-mentioned minerals should at least be accessible to a class, if not in the hands of each student; and it would be well if

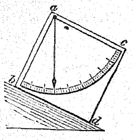
the collection were larger. Moreover, the instructor, if not a practical geologist, should have by him the writer's Manual of Geology, or some other large work on the science, in order to be ready to answer the questions of inquisitive learners, and add to the examples and explanations.

The student should possess a hammer and a chisel. The best hammer has the face square, flat, sharp-angled, and the opposite end brought to an edge; this edge should have the same direction with the handle (as in the figure), if it is to be used for getting out rock-specimens, but be transverse to this, and thinner, if for obtaining fossils.



The socket for the handle should be large, in order that the handle may stand hard work. The chisel should be a stone-chisel, six inches long. Rock-specimens should be uniform in size, with straight sides; say two inches by three, or three inches by four. Fossils had better be separated from the rock if it can be done safely.

For measuring the dip, that is, the slope, of layers, an instrument called a clinometer is used, which can be had of the instrument-makers. It is a compass having a pendulum hung at the centre, the extremity of which swings over a graduated arc. In the best kind the compass is three inches in diameter and has a square base. A clinometer apart from the compass may be easily extemporized by taking (see figure) a piece of board, *a b c d*,



cut to an exact square (three or four inches each side), hanging a pendulum on a pivot near one angle (*a*), describing on the board, with one leg of the dividers on the pendulum-pivot, an arc of 90° (*b* to *c*), and then dividing this arc into nine equal parts, each to mark 10°, and subdividing these parts into degrees. Such a clinometer, well-graduated, is sufficiently accurate for good work.

Field work of the kind above pointed out makes the facts in the science real. It also teaches with emphasis the great lesson that existing forces and operations are in kind the same that have formed the rocks, the valleys, and the mountains. It thus prepares the mind to appreciate geological reasoning and comprehend the march of events in the earth's history.

NEW HAVEN, CONN., February 1, 1875.

TABLE OF CONTENTS.

PART III. — HISTORICAL GEOLOGY.

ILLUSTRATIONS.

The original sources of the larger part of the illustrations will be found stated in the author's Manual of Geology. Of the few not in the Manual, Fig. 11 is from a photograph taken by the artist of Powell's Expedition; Figs. 13 to 16, from the author's "Corals and Coral Islands"; Fig. 33, from H. J. Clarke's "Mind in Nature"; and Fig. 46, from an electrotype kindly furnished by the publishers of the "American Naturalist," Salem.

GEOLOGY.

THE word *Geology* is from two Greek words signifying *the story of the earth*. As used in science, it means an account of the rocks which lie beneath the surface and stand out in its ledges and mountains, and of the loose sands and soil which cover them; and also an account of what the rocks are able to tell about the world's early history. By a careful study of the nature and positions of rocks, and the markings or relics they contain, it has been discovered how the rocks themselves were made; and also how the mountains and the continents, with all their variety of surface, were gradually formed. And, further, it has been ascertained not only that the earth had plants and animals long before Man appeared, but what were the kinds that existed in succession through the long ages.

The subjects, therefore, of which geology treats are: —

I. The KINDS OF ROCKS.

II. The ways in which the rocks, valleys, mountains, and continents were made, — or CAUSES IN GEOLOGY, AND THEIR EFFECTS.

III. The events during the successive periods in the earth's history; that is, what making of rocks was going on in each period, what making of mountains and valleys, and what species were living in the waters and over the land in each, and how the world of the past differs from the world as it now is,—all of which subjects, and others related, are treated under the general head of HISTORICAL GEOLOGY.

PART I.

ROCKS, OR WHAT THE EARTH IS MADE OF.

Rocks consist of minerals; and the ores and gems they contain are minerals. Any mineral that yields a metal profitably is called an *ore*.

The following are the characters of some of the kinds that are of most importance in geology.

I. — Minerals.

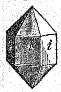
1. Consisting of Silica.

Quartz. — Quartz is the most common of the materials of rocks. It is well fitted for this first place; for (1) it is one of the hardest of minerals, the point of a knife-blade or edge of a file making no impression on it; (2) it does not melt in the hottest fire; and (3) it is not dissolved by water, or corroded by either of the common acids. Its durability is its great quality. With a piece of quartz it is easy to write one's name on glass. Another quality of it, distinguishing it from many minerals it resembles, is that it breaks as easily in one direction as another.

It is of various colors and kinds. *Flint* and *hornstone* are dark-colored massive quartz. The smooth-surfaced stones of a pebble-bank, whether white, brown, yellow, or black, if uniform (not speckled) in color, are almost all quartz. Mountains thousands of feet high are sometimes made of quartz rocks. The sands of a sea-shore are mostly quartz, because the grinding of particle against particle which goes on under the heavy dash or swift flow of the waters wears out all other materials, and leaves only the hard quartz particles behind.

Quartz is often found in crystals. The figure annexed shows the form of one of them. It is a regular 6-sided prism (*i i i*), with a 6-sided pyramid at each end; and it is often as transparent as glass. Frequently the crystals are attached by one end in great numbers to a surface of rock, so that this surface is brilliant with little pyramids of quartz set crowdedly over it, or with pyramids raised on prisms. The inclination of the face of the prism to the adjoining face of the pyramid is always the same (141° 47′), wherever the quartz crystal may come from. These glassy crystals are wholly natural productions, having their forms perfect and lustre brilliant when first taken from the rocks.

Fig. 1.



Quartz.

While some quartz crystals are clear and colorless, others have a purple color, and these are the *amethyst* of jewelry. Others have a light-yellow color, looking like topaz, and are called *false topaz;* and others a clear smoky-brown color, and these are the *cairngorm stone* of Scotland.

Still other kinds of quartz are the *agates*, in which the color is arranged in thin bands or layers of different shades of color, as white, smoky-brown, red, etc.

The material of quartz is called in chemistry *silica*, from the Latin word *silex*, meaning *flint*.

Quartz, while so enduring, when pulverized and heated fuses easily with soda, potash, lime, magnesia, or oxyd of iron, and forms a kind of glass; and ordinary glass is made by melting together quartz sand and soda. Again, hot waters containing soda or potash in solution will dissolve silica, and on cooling deposit it again. The waters of hot springs usually contain silica, which they have taken, along with soda or potash, from some rock with which they have been in contact. Through deposits from such solutions (1) agates have been made; (2) fissures in rocks have been filled with quartz, and the fractures thus mended; and (3) the sands of sand-beds and gravel of gravel-beds have often been cemented into the hardest of rocks.

Opal is also silica, but it differs from quartz in being softer, of less specific gravity, and never crystallized; and in the precious opal it has a beautiful play of colors arising from internal reflections. The silica of diatoms and of some deposits made by geysers is in the state of opal.

2. Silicates.

Silica, while existing in rocks abundantly as quartz, also makes, on an average, a third of all their other minerals,

limestones excepted; that is, it exists combined with other substances, making various common minerals. These minerals containing silica are called *silicates*.

1. Feldspar. — The most universal of these silicates are the kinds called *feldspar*. Besides silica, a feldspar contains the elements of alumina, and of potash, soda, or lime. *Corundum* is nothing but alumina; and the beautiful gem *sapphire* is only a clear blue variety of it; and the hard *emery* used for grinding and polishing, and often in little emery-bags for sharpening needles, is the same. It is the hardest of all stones excepting the diamond, and hence it is a good companion for quartz or silica in rock-making. The two, silica and alumina, in combination together make minerals that are harder and no less infusible than quartz; but when combined also with potash, soda, lime, or iron, the minerals it forms melt more or less easily.

Feldspar has usually a white or flesh-red color, and sometimes might be mistaken for quartz. But (1) it is not quite so hard as quartz, though too hard to be scratched with a knife; and, besides, (2) it melts when highly heated; (3) it breaks in one direction with a bright even surface, brilliant in the sunshine, and also in another direction at right angles or nearly so to the former, but less easily, — a kind of fracture called, in mineralogy, *cleavage*. While quartz has no cleavage, feldspar has cleavage in two directions transverse to one another.

Common feldspar (called *orthoclase* in mineralogy) is a *potash-feldspar,* it containing the elements of potash along with those of alumina and silica; another is a *soda-feldspar* (*albite*); others are *soda-and-lime feldspars,* and one of these, called *labradorite,* is a constituent of many igneous rocks; and another is a *lime-feldspar.*

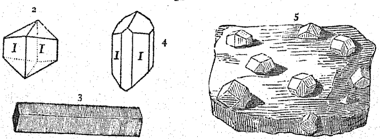
2. Mica. — Mica (often wrongly called *isinglass*) splits very easily into leaves thinner than the thinnest paper, which are tough and elastic, and frequently transparent. It does not melt easily, but fuses on the thin edges with high heat. It is the transparent material commonly used in the doors of stoves. Some mica is white, or gray; it is oftener brownish, and very frequently black. Like feldspar, it contains the elements of silica and alumina; the most common light-colored kind has, besides these constituents, potash; the black kind contains magnesia and iron.

3. Hornblende. — Black hornblende, when occurring in rocks, often looks much like mica, showing lustrous cleavage surfaces; but it is a brittle mineral, and hence cannot, like mica, be split into thin, flexible leaves or scales with the point of a knife. It makes very tough rocks, and hence the first part of the name, *horn;* the rocks are heavy and sometimes look like an ore of iron, and hence the second part, *blende,* a German word meaning blind or deceitful. It is a *silicate,* that is, it contains silica, but with it there are iron, magnesia, and lime. There are other kinds of hornblende, but they need not be mentioned here.

4. Augite.—Augite is black or dark-green *pyroxene*, having the same composition as hornblende, and differing only in the shape of its crystals. It is named from a Greek word signifying *lustre*, because its crystals are often bright, though not more so than those of hornblende.

Two of the crystals of hornblende are represented in Figs. 2, 3, and one of those of augite in Fig. 4. The angle of

Figs. 2-5.



Minerals.

Figs. 2, 3, Hornblende; 4, Augite; 5, Garnet in mica schist.

the prism of augite (or that between I and I in Fig. 4) is about 87°; while the angle of the prism of hornblende (between I and I in Fig. 2) is $124\frac{1}{2}$°; it is owing to this difference mainly that hornblende and augite have distinct names.

5. Garnet.—Usually in dark-red crystals, but often also black, and occurring imbedded in mica schist and other rocks; as represented in Fig. 5, contains silica, alumina, iron, and lime. When transparent it is used as a gem.

3. Carbon and Carbonates.

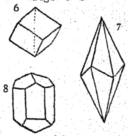
Carbon is familiarly known, though in a state not quite pure, as common charcoal. The *diamond* is *crystallized car-*

bon, and can be burnt like charcoal, though not without intense heat. *Graphite* (or *black lead*, as it is often badly named, since it contains no lead) is also carbon; it is the material of lead-pencils.

Carbon combined with oxygen in certain proportions forms *carbonic acid*, an ingredient of the atmosphere, it constituting 4 parts by volume of 10,000 parts of air; it is the gas that escapes from effervescent waters like soda-water. Its compounds are called *carbonates*.

1. Calcite.—Calcite occurs in crystals that break easily in three directions, affording forms with rhombic faces, like Fig. 6; the angles between the faces are 105° 5′ and 74° 55′. A very common form is called *dog-tooth spar;* the shape is shown in Fig. 7. Another kind is a 6-sided prism with a low pyramid at either end (Fig. 8). Calcite is easily scratched with the point of a knife. In a rock form, it is limestone.

Figs. 6-8.



Calcite.

When calcite or limestone is burnt, carbonic acid escapes as a gas, and lime (called *quicklime*, the material that slacks in water and is used for making mortar) is left. Calcite is *carbonate of lime*. When a grain of calcite is put into dilute hydrochloric (muriatic) acid, carbonic acid gas is given off freely, producing a brisk effervescence, and the calcite becomes wholly dissolved if it is pure. By means of (1) its effervescence with acid, (2) its low degree of hardness, (3)

its infusibility in the hottest fire, and its burning to quicklime instead, calcite or limestone is easily distinguished from feldspar and other minerals. The cleavages in calcite also separate it from feldspar; for the number of directions is *three*, and the angle between them is about 105° instead of about 90°.

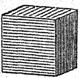
2. Magnesian Limestone, or **Dolomite.**—Limestone sometimes contains magnesia in place of part of the lime, and it is then called, in mineralogy, *dolomite*, after Dolomieu, a French geologist of the last century. Dolomite, or magnesian limestone, does not effervesce freely unless the acid is heated, and in this respect it differs from calcite. In aspect, calcite and dolomite are closely alike.

4. Ores.

The following are a few of the common ores.

1. Pyrite.—Pyrite has nearly the color and lustre of brass. It is so hard that it will strike fire with steel (whence its name, from the Greek for *fire*), and in this it differs from a yellow ore of copper, called chalcopyrite or copper pyrites, which it much resembles. It is very often in cubes, like Fig. 9. It consists of sulphur and iron, nearly 48 parts by weight in 100 being iron. Both of these elements have a strong affinity for oxygen; and consequently pyrite often changes to vitriol, or else forms the oxyd of iron called limonite.

Fig. 9.



Pyrite.

It is of no use as an ore of iron, because of the difficulty of separating the sulphur; but it is often employed for the making of vitriol (sulphate of iron). It is the most generally distributed of all metallic minerals, occurring in particles through most rocks, crystalline as well as uncrystalline. Owing to the tendency to alteration just mentioned, it has caused the destruction or disintegration of rocks over the earth's surface to a greater extent than any other agency.

2. **Magnetite,** or **Magnetic Iron Ore.** — An iron-black ore of iron, having a *black* powder. It is attractable by the magnet. It is common in Northern New York, Orange County, New York, Sussex County, New Jersey, and many other regions. It consists of oxygen and iron in the proportion of 4 atoms of the former to 3 of the latter, and contains 72 parts of iron in 100.

3. **Hematite,** or **Specular Iron Ore.** — A steel-gray ore of iron, but often also bright red, the powder being *red*. Red ochre is an earthy hematite. It is not attracted by a magnet. Like magnetite, it occurs in great beds in Northern New York, in the Marquette region, near Lake Superior, in Michigan, and many other places. It consists of oxygen and iron in the proportion of 3 atoms of the former to 2 of the latter, and contains, when pure, 70 parts by weight of iron in 100.

All rocks of a reddish or red color owe the color to this oxyd of iron.

Hematite and magnetite occur, with small exceptions, in beds instead of veins. When the beds are vertical or nearly so they look like veins.

4. **Limonite.** — A brown, brownish-yellow, or black ore of iron, affording a *brownish-yellow* powder, sometimes called *brown hematite.* Yellow ochre is impure or earthy limonite. It differs in composition from hematite only in containing water; and if heated the water is driven off, and it becomes red, or hematite. It contains, when pure, about 60 per cent of iron. It is a result of the decomposition of other iron ores, and forms great beds in some regions, as near Salisbury in Connecticut, and Richmond in Massachusetts. It is often found in bogs, and is then called *bog-iron ore.* Limonite is often disseminated through clays, giving them a yellowish or brownish color; and such clays when heated turn red, because they lose the water which makes limonite to differ from hematite. This is the reason that bricks are usually red. Clay for making white pottery must contain no iron.

5. **Siderite,** or **Spathic Iron Ore.** — A gray to brown ore, without metallic lustre, consisting of oxyd of iron and carbonic acid. When pure about 48 parts in 100 are iron. It occurs crystallized, and also in impure massive nodular forms. The iron ore of many coal regions is this massive nodular variety. It is a heavy mineral (the specific gravity 3.5 or above), and by this quality it may be distinguished from other grayish or brownish stones. In heated hydrochloric acid it

effervesces, owing to the escape of carbonic acid. This ore, like limonite, is sometimes present sparingly in clays.

6. Chalcopyrite, or **Yellow Copper Ore.** — A brass-colored mineral consisting of sulphur, iron, and copper, about a third of which is copper. It is scratched easily with a knife, and affords a dark-green powder, and thus differs from pyrite, which it resembles. It occurs for the most part in veins with other ores.

7. Galenite, or **Lead Ore.** — A lead-gray ore, brittle and easily pulverized, and affording a lead-gray powder. It often cleaves into cubic or rectangular forms. It is the common lead ore. It often contains a little silver, and is sometimes worked as a silver ore. It occurs in cavities in limestones, as in Northern Illinois, Wisconsin, and Missouri, and in Derbyshire, England; and is often found also in veins with other ores.

II. — Kinds of Rocks.

The following are the characters of some of the common kinds of rocks.

1. Limestone; Magnesian Limestone.—These rocks are partly described on pages 9 and 10. They are of dull shades of colors, from white through gray, yellow, red, and brown to black, and of all degrees of texture, from that of flint to a coarse granular texture. The test by acids, by heat, and by a use of the point of a knife in trial of the hardness,

are the means of distinguishing limestones from other rocks. *Chalk* is limestone. Ordinary marble is limestone, and sometimes the magnesian kind.

The different kinds of limestone are called *calcareous* rocks, from the Latin *calx*, meaning *lime*.

2. Sandstone. — Sandstone is a rock made of sand. The sand may be quartz, like the sand of most sea-shores, or pulverized granite or other rock; when gathered into beds and consolidated, it makes sandstone. Sandstones are the most common of rocks. They have various dull colors, from white through gray, yellow, and brown to brownish-red and red.

3. Conglomerate. — A conglomerate or pudding-stone is a consolidated gravel-bed, — gravel being sand mixed with pebbles or small stones. The stones are sometimes large, even a foot in diameter. They are often of quartz, sometimes of other hard rocks, and occasionally of limestone.

4. Shale. — Shale is a fine mud or clay consolidated into a rock having a slaty fracture, but less evenly slaty and less firm than true slate. The colors vary, like the colors of mud or clay, from gray and yellowish shades through red and brown to black. Black is a common color, because the plants and animals that live and die in the mud or over it contain carbon, the chief element of coal, and contribute portions of carbonaceous substances to the mud. Such black shales, when burnt, usually become white or nearly so, because the vegetable or animal material is then burnt out. For the same reason black limestones afford white quicklime.

The loose earthy material of the world, in and out of the water, is mostly either sand, gravel, mud, or clay; and thus it has been through all ages. *Sand* is finely pulverized rock. *Mud* is the same, for the most part; but it may contain rock that is decomposed as well as pulverized. *Clay* is a fine kind of mud; it is mainly either pulverized feldspar along with quartz in fine grains, or else decomposed feldspar with more or less quartz. It comes from the pulverizing of granite, gneiss, and other rocks containing feldspar, or from their decomposition. Clay often contains iron; and when burnt to make brick it then becomes red. *Gravel* is mixed sand and pebbles.

The consolidation of sand makes *sandstones;* of pebble-beds, *conglomerates;* of fine mud or clay, *shale.*

5. Argillaceous Sandstone. — When sands are clayey, the beds make, when consolidated, a clayey, that is, *argillaceous,* sandstone (*argilla,* in Latin, meaning *clay*). Such sandstones usually break into thin slabs, in which case they are said to be *laminated* sandstones; and, if of sufficient hardness, they make good flagging-stone for sidewalks. The common flagging-stone used in New York and adjoining States is an argillaceous sandstone.

6. Slate. — Slate, or *argillyte,* differs from shale in breaking much more evenly, and being much firmer. The slates used for roofing are examples.

7. Granite. — Granite is one of the *crystalline* rocks, its

ingredients being, not worn grains like those of a sandstone or conglomerate, but crystalline grains, — all having been rendered crystalline together by a process in which heat was concerned (p. 26). It consists of grains of three minerals, *quartz, feldspar, mica,* mixed promiscuously together. The quartz grains are usually grayish or smoky in color (commonly of a darker tint than the feldspar), and have *no cleavage.* The grains of *feldspar* have cleavage, and therefore show smooth, sparkling surfaces when a fragment of granite is exposed to the sun, and their color is usually white or flesh-red. The *mica* is much softer than the feldspar, and with a point of a knife-blade its grains may be divided into thin, flexible scales; its colors are white, brownish, or black.

8. Gneiss. — Gneiss has the same constituents as granite; but these constituents are arranged more or less in planes, and, owing to the mica, the rock splits into thick layers, and on a cross fracture appears banded. On account of its splitting into layers gneiss is said to be a *schistose* rock (this term being derived from a Greek word meaning to divide, and pronounced as if spelt *shistose*). This schistose structure is the only one distinguishing it from granite. It is somewhat like the laminated structure.

9. Mica schist. — Mica schist has the same constituents as granite and gneiss, but the quartz and mica are much the most abundant, and especially the mica; and on account of the large proportion of mica, mica schist divides into thin

layers. It glistens in the sunshine, owing to the scales of mica. Sometimes the scales of mica are indistinct, and then it is called *mica slate*.

The crystalline rocks, granite and gneiss, and gneiss and mica schist, pass into one another through indefinite shadings. There are granites that are slightly gneiss-like, and all grades to true gneiss; and there are all grades from gneiss to mica schist, so that it is sometimes difficult to say whether a rock should be called granite or gneiss, and whether another should be called gneiss or mica schist. Again, mica schist shades off through mica slate into argillyte, or clay slate, as the crystalline texture is less and less apparent.

10. Syenyte. — Some granite-like rocks contain *hornblende* in place of the mica, and such kinds are called *syenyte*. The hornblende is grayish-black, greenish-black, or black, and differs from black mica in being brittle, and hence in not affording thin, flexible scales. This fact indicates the kind of examination to be made to distinguish syenyte from granite. The so-called granite of the Quincy quarries, near Boston, and the red Scotch granite imported for monuments, are syenyte.

11. Syenyte Gneiss; Hornblende Slate. — Syenyte gneiss differs from ordinary gneiss in containing hornblende instead of mica. *Hornblende schist* or slate is a black slaty rock consisting mainly of hornblende.

12. Trap; Volcanic Rocks. — *Trap* is an igneous rock: that is, it has cooled from fusion, like the lavas of a volcano. It came to the surface in a melted state, through an opened fissure, from some deep-seated region of liquid rock. The part filling a fissure is called a *dike*. It has sometimes flowed from the fissure over the adjoining country. Trap is a dark-colored, heavy rock, more or less crystalline in texture. It consists of a lime-and-soda feldspar (called *labradorite*, from Labrador, where it was first found) and augite, along with grains of magnetite. It is the rock of the Palisades along the west side of the Hudson River above New York, of Mount Holyoke near Northampton, and various other hills and ridges in the Connecticut Valley; of many ridges in the vicinity of Lake Superior, and over the western slope of the Rocky Mountains; of the Giant's Causeway on the north coast of Ireland, and Staffa on the western coast of Scotland; and is common over the globe.

Some trap contains small nodules consisting of different minerals. These nodules fill cavities that were made, while the rock was still melted, by expanding vapors. This variety of trap is called *amygdaloid*, because the little nodules sometimes have the shape of almonds (*amygdalum*, in Latin, meaning *almond*). Trap, especially if very fine grained, is often called *basalt*. It frequently occurs in columnar forms, as at the Giant's Causeway, many places in the Lake Superior region, and elsewhere.

Volcanic rocks, called *lavas*, are those that have been ejected in a melted state from, or about, an open vent called (from the Latin for *bowl*) a *crater*. Eruptions around the crater make the fire-mountain, or *volcano*.

The larger part of lavas, and of all igneous rocks, are similar in composition to trap, although often very cellular rocks, and sometimes resembling much the scoria of a furnace.

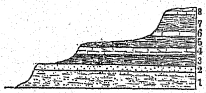
Other volcanic and igneous rocks are mainly feldspar in composition, and as they therefore contain little or no iron, they are less heavy than trap. Their specific gravity is mostly 2.5 to 2.8, while that of the trap series is 2.8 to 3.2. A common kind, rough on a surface of fracture, is called *trachyte;* and another, containing isolated crystals of feldspar, is *porphyry*.

Sand-rocks made out of volcanic sands are called *tufas*.

III. — Structure of Rocks.

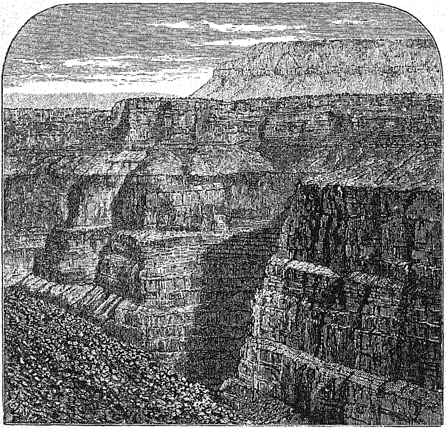
1. Stratified Rocks. — Most rocks consist of layers piled one upon another; and the series in some regions is thousands of feet in height. Figure 10 represents a bluff on the Genesee River at the falls near Rochester. In this section Nos. 1 and 2 are sandstone; No. 3, green shale; No. 4, limestone; No. 5, shale; No. 6, limestone; No. 7, shale; No. 8, limestone again.

Fig. 10.



Section on Genesee River.

Fig. 11.



Part of the wall of the Colorado Cañon, from a photograph by Powell's Expedition.

Another example is here presented (Fig. 11) from the Colorado Cañon. The height of the pile of layers in view is over 3,110 feet; but the river flows 2,755 feet below, and hence the whole height of the wall is 5,865 feet. Still another example from the Colorado region is given on page 78.

It is to be noted that (1) the layers were made one after another, beginning with the lowest; that (2) the successive layers correspond to successive intervals of time in geological history.

Rocks consisting thus of beds are called *stratified* rocks, from the Latin *stratum*, meaning *bed*.

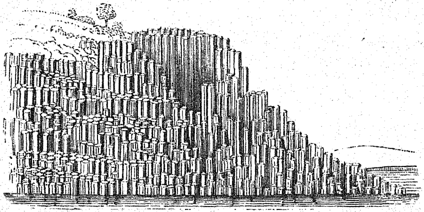
But layer and stratum in geology have not the same meaning. In Fig. 10 the lower sandstone bed, No. 1, consists of *many layers;* together they make a *stratum*. No. 3 is another stratum,—one of shale; No. 4, another,—one of limestone, and also made up of many layers; and so on. Thus there are *eight strata* (*strata* being the plural of *stratum*) visible in the bluff; and each consists of many layers. All the layers *of one kind*, lying together, make *one* stratum.

Sandstone, shale, conglomerate, and limestone are the most common kinds of *stratified* rocks. Gneiss and mica schist are also of this nature, although crystalline in texture.

2. Unstratified Rocks. — Unstratified rocks are not made up of layers. The granite about the Yosemite, in California, is in lofty mountains and mountain-domes, showing no distinct bedding or stratification; and the same is the character of most granite. The trap-rocks of the Palisades, on the Hudson, rise boldly from the water and have no division into layers; but, instead, a vertical division into imperfect columns, — a common feature of such trap-rocks, illustrated on the next page. It is not, however, true that all igneous rocks are *un*stratified; for where lavas have flowed out in successive streams over a region, those streams have made successive beds, and the rocks are truly stratified. But the term *stratified rocks* is usually applied only to the kinds not of igneous origin.

The columnar structure of some trap-rocks is well illustrated in the following view of a scene on the shores of Illawarra

Fig. 12.



Basaltic columns, coast of Illawarra, New South Wales.

in New South Wales, Australia. While stratification has come from the successive formation of beds, these columns are a result of the cooling. Cooling causes contraction, and the contraction of the solid rock as cooling went on produced the fractures. These fractures are always at right angles, or nearly so, to the cooling surfaces. Where the rock fills vertical fissures, the columns are horizontal. Even sandstones have been rendered columnar where overlaid by beds of trap, or when they have been subjected otherwise to heat.

PART II.

CAUSES IN GEOLOGY, AND THEIR EFFECTS.

UNDER the head of Causes, Geology treats of the ways in which (1) rocks, (2) valleys, (3) mountains and continents were made; or, in general, the means through which all changes have been brought about.

I. — Making of Rocks.

THE rocks, briefly described in the preceding pages, have been made by the following methods.

1. **Rocks formed from fusion.** — Igneous rocks are here included, or those that have cooled from a melted state after ejection from some seat of fire within the earth. They are crystalline in texture, each grain being a separate crystal; yet the small grains are so crowded together that they have nothing of the external forms of crystals, and sometimes they are too minute to be easily distinguished. Igneous rocks are of small extent and importance over the globe compared with those made through the action of water.

2. **Rocks made by deposition from waters holding the mate-**

rial of them in solution. — Waters containing lime often deposit it, and so make a kind of limestone.

Waters percolating through the limestone roofs of caverns, as they evaporate on the roof, form long pendent cones or cylinders of limestone called *stalactites* (from the Greek for *to distil*); and the same waters, dropping to the floor of the cavern, there evaporate and produce a bed of limestone called *stalagmite*.

There are many springs, and a few rivers, in the world, whose waters are calcareous. They petrify the moss, leaves, and nuts of swamps, and sometimes make thick beds which are very porous, and irregular in thickness and texture, called *calcareous tufa*, and also *travertine*. On Gardiner's River, in the Yellowstone Park, at the summit of the Rocky Mountains, such deposits are forming, and the river is thus made into a series of waterfalls. But such beds of limestone are of even less extent and importance than igneous rocks. None of the great limestones of the world were thus made.

Waters often hold traces of silica in solution, especially if hot and alkaline, and deposit it again, making siliceous beds and petrifactions. Some facts on this point are mentioned beyond, among the effects of heat in rock-making. Cold water seldom deposits silica unless where there are the remains of siliceous infusoria, as mentioned on page 38.

3. Rocks made by the mechanical agency of waters and winds, exclusive of limestones. — Far the larger part of rocks

are *fragmental* rocks; that is, they are rocks made out of *fragments* of older rocks. The finest mud or clay consists of fragments of rock-material, and hence a shale — a rock made from fine mud or clay — is a fragmental rock as much as a sandstone or conglomerate.

A large part of the fragments — or the sand, pebbles, mud — were made by the wearing action of moving waters; and hence such material is called *detritus*, from the Latin, meaning *worn out*. The agency of greatest effects and longest action in past time has been the *ocean;* that of next importance, *rivers;* that next, *winds*. But, preparatory for these agencies, the air, moisture, and the sun's heat have been always quietly at work giving aid in the reduction of rocks to fragments or grains; and thus the ocean, rivers, and winds have found much loose material ready for them, instead of being left to make all that was required for their work in rock-making.

The sand, gravel, and mud or clay of which rocks have been made were in general deposited as a sediment from the waters of the ocean or rivers, as will be explained further on; and hence sandstones, conglomerates, and shales are called *sedimentary* rocks.

4. Rocks made mainly or wholly of organic remains, that is, of the remains of plants or animals. — (1) The great *limestones* of the world are of this origin; also (2) some siliceous deposits; and (3) the coal-beds and peat-beds of the

world. Many sandstones and shales contain more or less of such remains. Plants, shells, and other distinguishable relics of living species found in rocks are called *fossils*, or *organic remains*. They are sometimes called also *petrifactions*, which means *made of stone*; but not always rightly so, for most fossils consist of the same material essentially that they had when in the living species. Wood is sometimes changed to stone; and this is then a true petrifaction.

5. Metamorphic Rocks. — Fragmental rocks, such as sandstones, shales, and conglomerates, and also limestones, have sometimes been altered (or metamorphosed), over regions of great extent, to *crystalline* rocks, such as granite, gneiss, mica schist, granular limestone or architectural marble; and these crystalline rocks are hence called *metamorphic* rocks, the word *metamorphic* meaning *altered*.

In describing these methods of making rocks the following order is here adopted: —

1. The ways in which plants and animals have contributed to rock-making.
2. The results from the quiet working of air and moisture.
3. The work of winds.
4. The work of rivers.
5. The work of the ocean.
6. The work done by ice.
7. The work of heat.

I. Ways in which Plants and Animals have contributed to Rock-making.

1. Making of Limestones.

The animal relics that have contributed most to limestones are *shells, corals, crinoids,* and *foraminifers.* These are secretions of animals, that is, stony portions of the body, either made internally in the same manner as the bones of a dog are made, or, like a shell, made externally as a covering for the animal. When the animal dies, the relics pass to the mineral kingdom and are used in rock-making; and, as stated above, nearly all the limestones have thus been made.

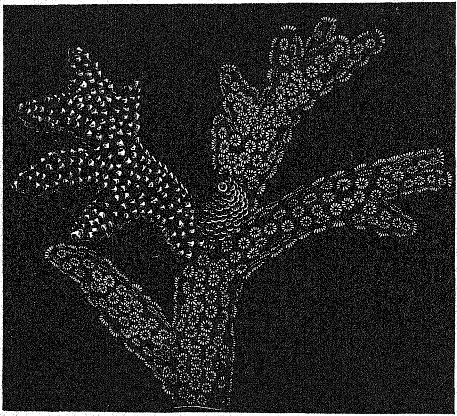
Corals and crinoids are exclusively oceanic species of animals; but, while this is true also of most shells and foraminifers, there are some kinds that flourish in fresh waters, and among shells some, like the snail, live over the land.

Shells are the secretions of animals related to the oyster, clam, snail, and cuttle-fish, — animals that have a *soft fleshy body,* and hence are called *Mollusks,* from the Latin *mollis, soft.* The shells serve to protect the soft body and give it rigidity.

Coral is, for the most part, the secretion of polyps, the most flower-like of animals, and it is an *internal* secretion. One of the branching corals, covered over (one branch excepted) with its numerous little flower-animals, is represented in Fig. 13. Branching corals of this nature are common in the

tropical Pacific, and are called *Madrepores*. Another kind, massive instead of branching, is shown in Fig. 14. The whole surface is a surface of flower-animals or polyps; in reference to its star-like cells, this kind is called an *Astræa*. The

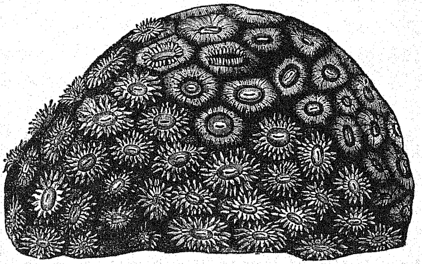
Fig. 13.



Madrepora aspera D.

expanded animals (only part of which in the figure are in this state) are like flowers also in their bright colors. The little petal-like arms (tentacles), in Fig. 13, are tipped with emerald-green, in the living state; and some Astræas are purple or

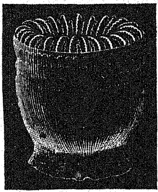
Fig. 14.



Astræa pallida D.

crimson with an emerald centre, and others have other bright tints. While so much like flowers in appearance, polyps are wholly animal in nature. Each polyp has a mouth at the centre above, as shown in Fig. 14; and it eats and digests like other animals. Another kind of coral is represented in Fig. 15, without the animal; it shows the radiating plates in the cup-shaped cavity at top. Still another, somewhat larger, elliptical in shape instead of cylindrical, and in the living state, is presented in Fig. 16. The mouth is a very long one, and the arms or tentacles which serve to push in the prey it cap-

Fig. 15.

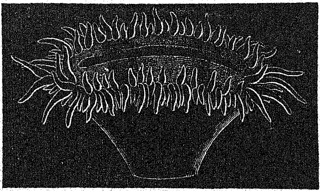


Thecocyathus cylindraceus Pourtales.

tures are also long. It owes much of its power of capturing to the stinging qualities of these tentacles.

The arrangement of the tentacles of a polyp around a centre, and also that of the plates inside of the coral cup, is radiate; and hence Polyps, like some other kinds of life, are called *Radiate* animals.

Fig. 16.

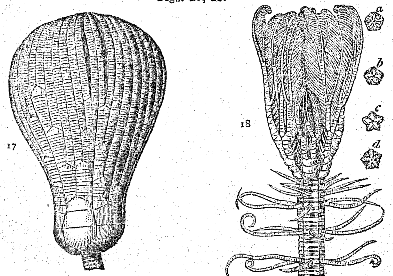


Flabellum pavoninum.

Crinoids. — Crinoids also are flower-like animals, and *Radiates*. They were once exceedingly abundant in the seas of the world, but now are rarely to be found. Two of the kinds are represented in Figs. 17 and 18, the first an ancient species, and the second a modern one from the seas of the West Indies. The arms above are arranged around a centre like the petals of a flower, and, like them, they may be opened out wide or closed up so as to look like a bud; and this the animal does at will. Below the radiating head-bearing part there is a stem, sometimes a foot or more long, which, if the animal is

alive, is planted below on the solid rock, or in the mud of the sea-bottom. Crinoids differ in many respects from polyps. One point is this: the coral which a polyp makes is all one

Figs. 17, 18.



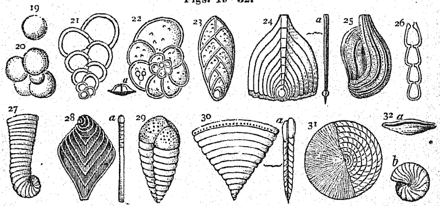
Crinoids.

Fig. 17, Zeacrinus elegans; 18, Pentacrinus caput-Medusæ, now living in the West Indies; *a–d*, calcareous disks or plates of the stem, showing their 5-sided form.

piece, whether massive or branching; while the stony secretion of the crinoid is in multitudes of pieces. The stem is a pile of little disks often circular and looking like button-moulds, as in Fig. 17; but sometimes 5-sided, as in Figs. 18 *a*, *b*, *c*, *d*, showing some of the forms. The arms also are made up of stony pieces. The cross-lines on the arms in the above figures indicate the number of pieces of which each is made. The pieces are held together by animal membrane as long as the animal lives; but when it dies, the pieces usually fall apart, and are scattered by the moving waters.

Foraminifers. — Foraminifers are made by the simplest of all animals, and very minute kinds, — animals that have no organs of sense, and in general not even a mouth to eat with. When a particle of the desired food touches the body, and is perhaps held there by its power of stinging, that part of the body begins to be depressed, and continues to sink inward until the food is in a cavity inside made for the occasion; then the food is digested, and any part of it not digested is thrown out by restoring the body to its former state. Some

Figs. 19 - 32.



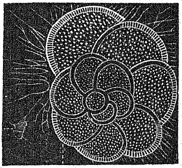
Rhizopods.

Fig. 19, Orbulina universa; 20, Globigerina rubra; 21, Textilaria globulosa; 22, Rotalia globulosa; 22 *a*, side-view of Rotalia Boucana; 23, Grammostomum phyllodes; 24, Frondicularia annularis; 25, Triloculina Josephina; 26, Nodosaria vulgaris; 27, Lituola nautiloides; 28 *a*, Flabellina rugosa; 29, Chrysalidina gradata; 30 *a*, Cuneolina pavonia; 31, Nummulites nummularia; 32 *a*, *b*, Fusulina cylindrica.

of the shells are represented much enlarged, excepting the last three, in Figs. 19 to 32. Many of these animals have the faculty of extending out, at will, feelers over the body that are a little root-like, and hence they are called *Rhizopods*, from the Greek for *root-like feet*. An enlarged view of one of

the species, with the fibre-like arms extended, is shown in Fig. 33. All of the shells above figured, excepting the last three, are no larger than the finest grains of sand; and yet they contain a number of cells, each of which corresponds to a separate one of the Rhizopod animals.

Fig. 33.



Rotalia veneta.

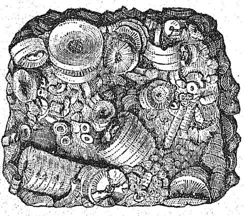
Fig. 31 is a large foraminifer shaped like a *coin*, and the Latin for coin, *nummus*, suggested for it the name it bears, — a *Nummulite*.

Shells, corals, crinoids, and foraminifers consist almost solely of carbonate of lime, — the material of limestone; and hence their consolidation makes limestone. Shells, corals, and crinoids are usually more or less ground up under the action of the waves or currents of the ocean, and thus reduced to fragments or sand, before they are consolidated. Much coral limestone of existing seas — the rock of coral reefs — shows no trace of the corals of which it was made, because all were ground by the aid of the waves and currents to a coral sand or coral mud before consolidation. But in other cases the rock contains fragments of the corals or crinoids, and sometimes entire specimens. Fig. 34 shows the aspect of a crinoidal limestone when the crinoidal remains are not wholly ground up; the disks and cylinders are portions of the stems of the crinoids. The coral reefs of the Pacific are coral-made limestones, and some of them

are hundreds of square miles in area and many hundreds of feet in thickness.

Foraminifers are so minute that they need no grinding in order to make a fine-grained rock. They live in sea-waters of all depths, and are especially abundant over the sea-bottom down to a depth of twelve or fifteen thousand feet, as has been proved by soundings in the Atlantic between Ireland and Newfoundland, and elsewhere. Chalk is made mainly of foraminifers, and was of deep-water origin; and chalk is now making, and has been through ages past, over the bottom of the ocean.

Fig. 34.



Crinoidal Limestone.

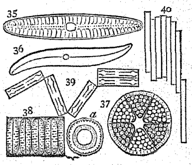
There are also some plants, of the order of Sea-weeds, that secrete lime, and which have thereby contributed to rock-making. Among these are included (1) coral-making plants, called *Nullipores*, — so named from the fact that, while looking like corals, they have no pores or cells; (2) *Corallines*, which are related to Nullipores, but have delicate jointed stems; (3) *Coccoliths*, which are microscopic calcareous disks, very abundant over some parts of the ocean's bottom and occurring also in shallower waters.

2. Making of Siliceous Rocks or Masses.

Some of the minutest and simplest of plants and animals make stony secretions of *silica* instead of carbonate of lime, and hence form out of their stony secretions beds of silica instead of beds of limestone. Although minute, often requiring a high microscopic power even to see them, such species have thus been large contributors to rock-making through all geological history. Many of them are remarkable for their beauty of form and texture.

The *plants* here included are called *Diatoms.* Nearly all are too minute to be distinguished without a lens. Some of the forms are shown, highly magnified, in the annexed figures, 35 – 40. They are strange forms for plants, and still are known to be of this kingdom of life. They have lived in such numbers over the bottoms of shallow ponds, marshes, and seas, that the infinitesimal shells have sometimes made beds scores of yards in thickness. The material of such beds looks like the finest of chalk. Owing to the hardness and extreme fineness of the grains, it was used as a polishing powder long before it was discovered that each particle was the secretion of a microscopic water-plant.

Figs. 35 - 40.

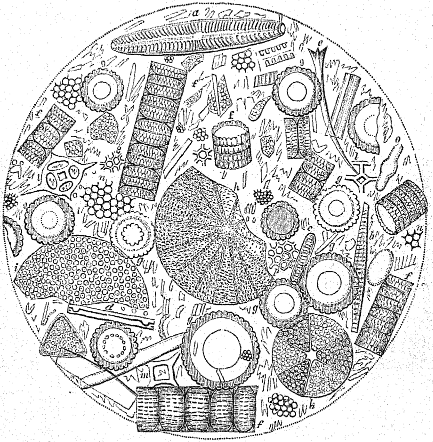


Diatoms highly magnified.

Fig. 35, Pinnularia peregrina, Richmond, Va.; 36, Pleurosigma angulatum, id.; 37, Actinoptychus senarius, id.; 38, Melosira sulcata, id.; *a*, transverse section of the same; 39, Grammatophora marina, from the salt water at Stonington, Conn.; 40, Bacillaria paradoxa, West Point.

It is obtained from the bottoms of many marshes, and sold for polishing; and the packages in the shops from beds in Maine are labelled *Silex*. A bed of great extent in Virginia,

Fig. 41.



Richmond Infusorial Earth.

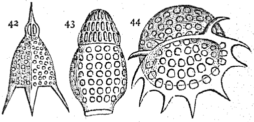
a, Pinnularia peregrina; *b*, *c*, Odontidium pinnulatum; *d*, Grammatophora marina; *e*, Spongiolithis appendiculata; *f*, Melosira sulcata; *g*, transverse view, id.; *h*, Actinocyclus Ehrenbergii; *i*, Coscinodiscus apiculatus; *j*, Triceratium obtusum; *k*, Actinoptychus undulatus; *l*, Dictyocha crux; *m*, Dictyocha; *n*, fragment of a segment of Actinoptychus senarius; *o*, Navicula; *p*, fragment of Coscinodiscus gigas.

near Richmond, is in some places thirty feet thick; and a little of the dust, under the microscope of Ehrenberg of Berlin, —

who first made known the nature of these polishing powders, — presented the appearance shown in the foregoing figure. These forms were all in the field of his microscope at one time. Nearly every particle is a Diatom or a fragment of one. Some beds near Monterey, in California, have a thickness exceeding fifty feet.

Among *animals* making siliceous shells, the following are examples. (1) A kind illustrated in Figs. 42–44, related to the foraminifers, the animals being Rhizopods, but differing in their forms, and in secreting silica instead of lime.

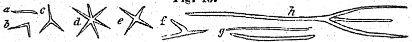
Figs. 42-44.



Polycistines.

(2) Most *Sponges*, for sponges are animal in nature. Ordinary sponges are made of horn-like fibres; but in the living state these fibres are covered thinly with an animal coating which is in reality a layer of microscopic animals hardly higher in grade than Rhizopods. In a large part of them these horny fibres

Fig. 45.



Siliceous spicules of Sponges.

are bristled with minute spicules of silica of various forms. A few of these forms are shown in Figs. 45 $a-h$. Some of the oblong pieces or fragments in Fig. 41, page 36, are spicules of ancient sponges.

Other sponges consist wholly of fibres of transparent silica, excepting a thin coating of animal material. One of these siliceous sponges from the bottom of the East India seas is represented in Fig. 46, but only half the natural size. The extreme delicacy of the structure might hardly be inferred from the figure; for the sponge looks as if made of spun glass, and as if too fragile to be handled. Such siliceous sponges are common over the bottom of the ocean, and at various depths below the reach of the waves, whose violence they could not withstand.

The *flint* of the world, or *hornstone* as the most of it is called (page 4), is nearly pure silica (or quartz), and, like quartz, it scratches glass easily. It is found imbedded in limestones and other rocks. It has been made for the most part out of diatoms and spicules of sponges, and without any unusual degree of heat. This fact shows that such deposits, when under water, may be partly dissolved by the cold waters, and then consolidated without any external aid beyond that afforded by the saline ingredients of the waters. By the same means shells and other fossils have often been changed to quartz, or have undergone a true petrification.

Besides shells, corals, crinoids, foraminifers, diatoms, and sponges, relics of various other kinds of animals are contained in rocks or have contributed to their material. These are the harder parts of Worms, Insects, Spiders, Centipedes, and of various Crustaceans (among these last, Shrimps, Crabs,

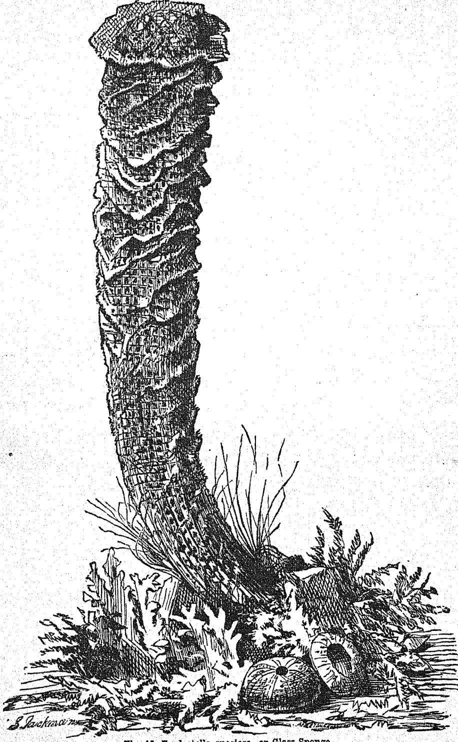


Fig. 46, Euplectella speciosa, or Glass Sponge.

and inferior kinds); the bones and scales of Fishes and Reptiles; the bones and occasionally the feathers of Birds; the bones of Quadrupeds of various kinds, and remains of various other forms of life; and, besides, the *tracks* of animals, from those of Worms and Insects to those of Quadrupeds and Man.

The living species of the globe that have contributed most to rocks are those of the waters, because rocks are mainly of aqueous origin; and chiefly marine species, because the greater part of rock-making has been performed by the ocean.

Oceanic life is in greatest profusion along the shallow waters off shore, down to a depth of a hundred feet, — the corals making coral reefs in our present seas not living at a greater depth than this. But there is abundant life at greater depths, and even over the ocean's bottom down to about 15,000 feet. Crabs with good eyes have been obtained from the sea-bottom at a depth of 5,000 feet; lobsters without eyes at a depth of 5,000 to 12,000 feet; and a few living mollusks from a depth exceeding 12,000 feet. Besides these species, there are through all these depths scattered Corals, Crinoids, and delicate siliceous Sponges related to that figured on page 39. But Rhizopods are the most abundant species (page 32), and with them there are the minutest and simplest of plants, Diatoms and Coccoliths.

3. Making of Peat-beds.

In marshy areas, where spongy mosses of the genus Sphagnum are growing luxuriantly along with other water-loving

plants small and large, and some kinds that can stand the water, but would thrive better were it drier, there are always deposits of leaves and stems and other remains of plants forming under the water. The moss, which is the chief plant in the increasing deposit, has the faculty of dying below while growing above; and thus its dead stems may be many yards long, while the living part at top is only six inches or so. The small plants and shrubs, and the trees, if such there be, shed their leaves and fruit annually, and these fall into the water. Annual plants die each year, and their stems are buried with the leaves. All the plants, the mosses excepted, sooner or later die, and thus branches and trunks are added at times to the accumulation in progress. Birds and quadrupeds may add their bones, and insects, with the various inferior kinds of life in such places, may become mingled with the other relics.

The materials of plants buried under water undergo a kind of smothered combustion. They become black, then, below, are reduced to a pulpy state, or rarely to an imperfect coal; and the mass thus altered constitutes what is called *peat.*

Dry woody material consists, one half of carbon, or the main constituent of charcoal, along with two gases, oxygen and hydrogen; and in the change the proportion of the gases to the carbon is diminished about one fifth. The black color — one result of the change — is due to the carbon, as in the case of the black color of soils, many muds, and black clayey and calcareous rocks.

The bed of peat sometimes increases until it is scores of yards in depth. Ireland is noted for its peat swamps; the "mosses," as they are called, of the Shannon, are fifty miles long and two to three broad. Peat swamps are common over all continents out of the tropics. The Dismal Swamp in North Carolina is a peat swamp from one end to the other; and no one has yet ascertained the depth of the peat.

The world has had its peat swamps in all ages since the first existence of abundant terrestrial vegetation; and they are the sources of all its coal-beds, each coal-bed having been first a peat-bed. But the kinds of plants concerned have varied with the successive ages.

2. Quiet Work of Air and Moisture.

When rocks are wholly under water, whether it be salt or fresh water, they are generally protected from decay. But if above the water, so that air as well as moisture has free access, nearly all become altered, and many crumble to sand or change to clayey earth. Blocks of some kinds of sandstone that would answer well for under-water structures, when left exposed to the air for a few years fall to pieces or peel off in great concentric layers. Crystalline limestone (white and clouded marble) in many regions covers the surface with marble dust from its decay. Gneiss and mica schist are among the durable rocks; and yet much of the gneiss and mica schist of the world undergoes slow alter-

ation, so that in some regions they are rotted down or have become soft earth or a gravel to a depth of fifty or a hundred feet, and even two or three hundred in tropical countries. This is the amount of decomposition produced in those places through a very long period of time, perhaps the whole time from the epoch of their elevation above the ocean. But it is no measure of the amount that would have taken place if the decayed portion had been removed as it was formed, as has often happened; for, in that case, alteration would have proceeded with greater rapidity because of the freer access of air and moisture.

The granite hills are often thought of as an example of the everlasting, as far as anything is so on the earth. But, while there is granite that is an enduring building-stone, a large part of the granite of the world becomes so changed on long exposure that the plains and slopes around are thence deeply covered with the crumbled rock, and great masses may be shivered to fragments by a stroke of a sledge. Many granitic elevations over the earth's surface have disappeared beneath their own débris.

Much trap-rock is as firm as the best granite. But other kinds are rotted down to a depth of many feet or yards, and sometimes only here and there a ledge shows itself above the ground as the remains of ranges of hills. Even the most solid trap, where exposed to the elements, has a decomposed outer layer, or is *weathered,* as the change is called. This

crust is often but a line or two deep and has everywhere the same depth over blocks of like kind. But this depth is constant, because, as the elements eat inward, there is as gradual a loss of the altered grains over the outer surface.

Thus invisible agencies are producing the slow destruction of the exposed parts of nearly all the rocks of the globe, even to the tops of the lofty mountains. The firmer kinds of slates (argyllite), some hard conglomerates and gneisses, and the compact limestones are the rocks that defy the elements most successfully.

In this way rocks have been prepared for the rougher geological work carried on by moving water and ice; and through the same means the earth or soil of the world has to a large extent been made.

This quiet work of air and moisture is really *chemical* work; and it is mostly performed through the chemical action of two ingredients present in them, — *carbonic acid* and *oxygen*. Other agencies aid in this slow destruction, as explained on pages beyond.

3. The Work of Winds.

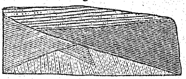
Winds, or moving air, carry sands from one place to another, and wherever the earth's surface is one of dry sand, and the winds blow strongest and longest in one direction, great accumulations of sand are made. Even when the windows of a house in a city are ordinarily kept closed, the dust

will get in. The west winds have driven the sands of the Desert of Sahara over parts of Egypt, and the ruins of ancient cities have thus been buried.

Sea-shores are often regions of sand, owing to the work of the waves. The heavy winds take up the loose, dry sands and carry them beyond the beach, to make ranges of sand-hills, often 20 to 30 or more feet high. Thence the hills frequently travel inland, through the same means, sometimes burying forests, as on the west coast of Michigan, sometimes overwhelming villages, as in England and France, leaving at times only the top of a church-spire to mark the site.

The stratification of a hill of drifted sands is so peculiar that it is easy to tell when sand-rocks have been formed through the agency of the winds. Fig. 47 represents a part of a section observed in the Pictured Rocks on the south shores of Lake Superior. The layers dip in many directions. Such a structure is owing to the accidents to which the sand-hills are exposed. A heavy storm — perhaps aided by heavy waves at high tide — often carries away part of a hill. Then the winds build it up anew, putting the successive drifts — which make the successive layers — over the new surface, differing much from the first in its slopes. The hill suffers from another storm, and is again built up during the period of quieter weather that follows. This

Fig. 47.



Part of a section of a drift sand-hill, showing the stratification.

may take place many times. The result is the kind of irregularity of stratification illustrated in the cut.

Sands carried by winds over rocks often wear the surfaces deeply, as noticed in the Colorado desert, in the Grand Traverse region near Lake Michigan, and elsewhere. This agency has scoured out gorges, shaped and undermined bluffs, and worn away rocks, in the dry parts of the Rocky Mountain region. Man has taken the hint, and now uses sand driven by steam to etch on glass and to carve granite and other rocks.

4. The Work of Fresh Waters.

Running water is at work universally over a continent wherever there is a slope to produce movement, and the clouds yield rain; and it acts with greatest energy where the slope is greatest, or about high hills and mountains.

The waters of the rains, mist, and dew about the mountain-tops descend in drops and rills, and then gather into plunging streamlets and torrents; the many torrents combine below into larger streams; and these, from over a wide region, unite to make the great rivers. The Mississippi has its arms reaching westward and northward to various summits in the Rocky Mountains, and eastward to the Appalachians; and its greatness is owing to the vast breadth of the area it drains. Not only mountains, but every small elevation over a land, and even its little slopes, have, when it rains, their rills combining into torrents, and these into larger streams, which flow off to join some river.

The waters of the clouds no sooner drop to the ground than they begin to work, tearing off and carrying away grains of earth from the rocks or slopes. The stronger rills act in this way with much greater effect; and the torrents move stones as well as earth. This work over the larger part of a country may be almost wholly suspended in the dry season. But when the rains set in the surface is alive with its workers, small and great. Torrents become increased immensely in depth and force, and earth and often rocks are torn up and borne along in vast quantities.

The more rapid the flow of the water the coarser the detritus it can transport; and as a stream slackens its rate the coarser material falls to the bottom, leaving only the finer to be carried on. Thus the large stones and then the smaller will drop as the torrent becomes less and less violent; but the earth and gravel may be borne on to the rivers; and these, in their times of flood, may carry a large part of the burden of earth to the ocean. Under such a rough-and-tumble movement stones are worn to earth and gravel, and in this pulverized state they may continue the journey seaward. A single heavy rain-storm has sometimes so filled the narrow gorges of a mountain that vast deluges of water, rocks, gravel, and trees have swept down, carrying away houses and spreading desolation over the plains below.

Through the wearing effect of rivers and their tributaries, reaching to every part of a continent, the mountains, ever

since their first emergence, have been on the move to the ocean, and we cannot judge of their former height from what now exists.

The process of erosion is often called, in geology, *degradation*, because mountains and hills are made low by it; and *denudation*, because it removes their exterior.

The average amount of sediment annually carried to the borders of the Gulf of Mexico by the Mississippi River has been stated to be 812,500,000,000 pounds, or enough to make a pyramid a square mile at base over 700 feet in height. This material is deposited about the mouth of the river, and is gradually extending it farther and farther into the Gulf. The fine sediment of rivers settles much more rapidly in salt water than in fresh, and this is one reason why this material is prevented from being carried off to the deep ocean.

The great area about the mouth of a large river over which these deposits are distributed is usually intersected by channels, and constitutes what is called a *delta*. Fig. 48 represents the delta of the Mississippi.

The channel of the river extends far into the Gulf of Mexico, and terminates in several mouths. The delta stretches northward nearly to the mouth of Red River, and has an area of about 12,300 square miles. The waves and currents of the Gulf act with the currents of the river in the deposition of the sediment.

The Mississippi is an example of what all rivers are doing,

each according to its ability. Some carry their detritus to lakes, to extend their shores, and aid in filling them. But much of

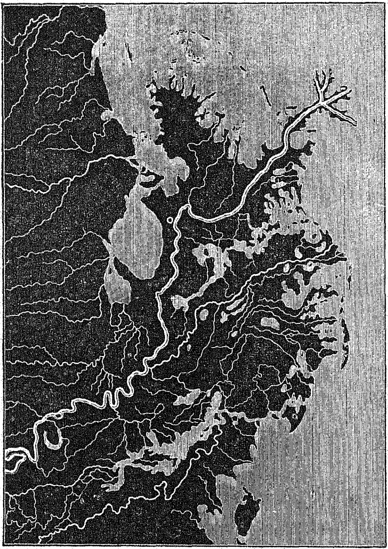


Fig. 48. Delta of the Mississippi.

the detritus is left on the various river-flats, and this part is called *allŭvium*. Again, a large part reaches the ocean, and

is distributed along the borders, making sand-flats, mud-flats, and ultimately good dry land, to widen the serviceable area of the continent.

The banks and bottom of a river are generally made of coarser or finer material, according to its rate of flow in the different parts. Where it is very slow the bottom and banks are sure to be of mud, for the very slow movement of the waters gives a chance for the finest detritus to settle; but if rapid it will consist of pebbles, if the region contains them. The bank struck by the current is, in general, more pebbly than the opposite.

The action of the waters of large lakes in rock-making is to a great degree the same as that of the ocean.

5. The Work of the Ocean.

The mechanical work of the ocean has been carried forward chiefly through (1) its tidal movements; (2) its waves; and (3) its currents.

1. Tides. — With each incoming tide the waters flow up the coast and into all bays and mouths of rivers, rising several feet and sometimes yards above low-tide level; and then, with the ebb, the same waters flow back and leave once more the mud-flats and sand-banks of the bays and coasts exposed to view. This retreat of the tide allows the rivers to discharge freely and carry out their detritus to sea; but soon again the inflow stops the movement outward and reverses it, and dur-

ing the time of slackened flow the waters drop their detritus, —part about the mouth of the stream, part along the adjoining coast, and part in the shallow waters of the sea outside.

2. **Waves.**—The sea in its quiet state is rarely without some swell, which causes at short intervals a gentle movement on the beach and some rustling of the waters along rocky shores. Generally there are waves and breakers; and when a heavy storm is in progress the waves rise to a great height and plunge violently upon the beach and against all exposed cliffs, wave following wave in quick succession through days or it may be weeks together. With each storm the waves renew their violent strokes, and in many seas the action is incessant.

The plunge on the beach grinds the stones against one another, rounding them and finally reducing them to sand, and the sand to finer sand. The waters after the plunge retreat down the beach underneath the new incoming wave; and this "undertow" carries off the finer sand made by the grinding to drop it in the deeper waters off the coast, leaving the coarser to constitute the beach.

Thus wave-action grinds to powder and removes the feldspar and other softer minerals of the sand, and leaves behind the harder quartz grains; and consequently, wherever there are beaches of sand, there are offshore deposits of mud made out of the fine material carried seaward by the undertow. In no age of the world have sand-beds been formed without the making of mud-beds somewhere in their vicinity.

The cliffs, or exposed ledges of rock, are worn away under the incessant battering, and afford new stones and sand for the beach, and the shallow waters adjoining. Most rocky shores, especially those of stormy seas, show, by their rugged cliffs, needles, arches, and rocky islets the effects of the storm-driven waves.

It is to be remembered that the ocean, as stated on page 42, often finds the work of destruction facilitated by the weakening or decomposition the rocks have undergone through the quiet action of air and moisture, and also through other means explained beyond (page 63).

The waves, as they move toward the shores over the shelving bottom, bear the sediment in the waters shoreward, and throw more or less of it on the beach. And thus the beach grows in extent. The sediment is, in general, either what it gets from the battered rocks of the coast, or what the rivers pour into the sea. At the present time the Atlantic receives an immense amount of detritus through the many large streams of Eastern North America; and as a consequence the shores are extensive sand-flats from New York southward, with shallow sounds inside; and the latter are the spaces not yet filled to the water-level with the deposits of detritus. The coast has been growing seaward for ages through the same means, with but little aid from the wear of sea-shore cliffs. But in the earlier geological ages this was not so; for the continent was to a large extent more or less submerged, and the waves

made a free sweep over its surface, battering the rocks in many places, and thus making its own sediment; for there were only small streams on the small lands to give any help.

In the warmer seas of the world *mollusks* are very abundant. The heavier storm-waves tear them from the muddy bottom where they were alive, and throw them on the beach. There they are exposed to the incessant grinding which stones and ordinary sands experience elsewhere, and thus are reduced to sand. Every storm adds to the shells of the beach as well as to the shell-sand. Thus sand-deposits form that are made out of shells alone; and they keep growing and may become of great extent. The finer shell-sand is swept out into the shallow waters, and there produces a finer deposit. The hardening of such deposits makes limestone; and the shells that happen to escape the grinding are its fossils. In this way limestones have been made in all geological ages. Shell rocks are now forming at St. Augustine, Florida, and the limestone there made is used as a building-stone.

In other parts of tropical seas there are *corals* growing profusely within reach of the waves, or within 100 feet of the surface. Many are broken or torn up by the waves and carried to the beach, and there are ground up and spread out in beach deposits and off-shore deposits. These beds of coral sand or mud harden, and then become the coral reef rock, — a true limestone, similar to many of ancient time. South of Florida, and in other parts of the West Indies, in various

parts of the tropical Pacific, and also in the East Indies and Red Sea, these coral limestones are now in progress.

3. Currents. — The ocean has its system of circulation, or of great currents. The Gulf Stream is part of it; its waters, flowing westwardly in the tropical Atlantic, bend northward as they pass the West India seas, and then pass northeastward, parallel with the North American coast as far as Newfoundland, gradually curving eastward. Thence a part continues either side of Iceland to the Arctic seas, from which there is a return, as a cold Labrador current, along the coast of Labrador and farther south. This great current moves but 5 miles an hour when swiftest, and this only in part of the straits of Florida. Its average rate, parallel with North America, is $2\frac{1}{2}$ miles an hour; and it is hardly felt at all anywhere along the sides of the continent, not even in the Florida straits. It hence gets no detritus from the wear of coasts, and is too feeble to carry anything but the very finest silt. The ocean's bottom shows that it receives almost nothing either in this way or from the currents of great rivers. When, however, the continents were submerged a few hundred feet or less in ancient time, the currents swept over the surface, and must have done much work in wearing rocks and transporting detritus.

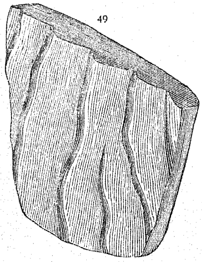
Both waves and gentle currents raise *ripples* over the sands; and such ripple-marks, made by the ocean in ancient times, are often preserved in the rocks (Fig. 49). They show that

the sands of which the rocks were there formed were within reach of waves or gentle currents.

The mud of a mud-flat or of a dried-up puddle along a roadside is often found cracked as a consequence of drying; and such *mud-cracks* are frequently preserved in sedimentary rocks (Fig. 50). They are of great interest to the geologist; for they show that the layer in which they occur was not of

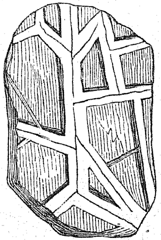
Figs. 49, 50.

49



Ripple-marks.

50



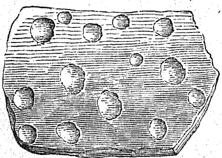
Mud-cracks.

deep-water origin; but beyond question was exposed, for a while at least, above the water's surface to the drying air or sun, as mud is now often exposed along a roadside, or over the mud-flats of an estuary. Such cracks become filled with the next deposit of detritus, and this filling has often been afterward so consolidated as to be harder than the rock outside; and hence on a worn surface the fillings of the cracks

generally make a network of little ridgelets, as in the preceding figure.

Again, mud-flats sometimes have the surface covered with rain-drop impressions after a short shower in which the drops were large; and many shales (rocks made of mud or clay) retain these markings (Fig. 51); others have impressions of the *footprints* of animals, even those of insects.

Fig. 51.



Rain-drop impressions.

Such delicate impressions are preserved, because soon after they are made they become covered with a layer of fine detritus; and after that nothing can erase them short of the removal of the deposit itself.

The rocks that have been made by fresh waters and the oceans are of vast extent. They are the sandstones, conglomerates, and shales of the world; and they include the limestones also. The ocean has done far the larger part of the rock-making. In the earlier geological ages it worked almost alone; for the lands were very small, and only large lands can have large rivers and river deposits. Afterward, in the coal-era, there was at least one large delta or estuary on the borders of the American continent,—that of the St. Lawrence; and ever since rivers have given important aid. During the last of the ages, after the continents had reached nearly their present extent,

and the mountains their modern height and numbers, rivers have done the larger part of the distribution of rock-material.

Sedimentary rocks show that they were formed through the action of water, often in the rounded or water-worn pebbles they contain, or the water-worn sand, or from a resemblance in constitution to a consolidated bed of mud or clay; in their relics of aquatic life, and the indications of wave-action or current-action above pointed out; and in their division into layers, such as exist in known sediments or deposits from waters.

6. The Work of Ice.

1. Expansion on freezing. — When water freezes it expands. If it freeze in a pitcher, the expansion is pretty sure to break the pitcher. If it freeze in the crevice of a rock, it opens the crevice; and by repeating the process winter after winter in the colder countries of the globe, it pries off and breaks apart rocks, and makes often a slope of broken blocks, or *talus*, at the foot of a bluff. By opening cracks in this way it gives air and moisture new chances to do their quiet work of destruction.

2. Transportation by the ice of rivers or lakes. — When water freezes over a river it often envelops stones along the shore; and then, whenever there is a breaking up, the ice with its load of stones is often floated off down stream; or if the water of a stream or lake rises in consequence of a flood, the stones may be carried farther up the shore and dropped there.

In cold countries ice often forms thickly about the stones

in the bottom of a stream; and as it is lighter than water it may become thick enough to serve as a float to lift the stone from the bottom, so that both ice and stone journey together with the current.

These are commonplace ways in which ice does geological work. Its greater labors are performed when it is in the condition of a glacier.

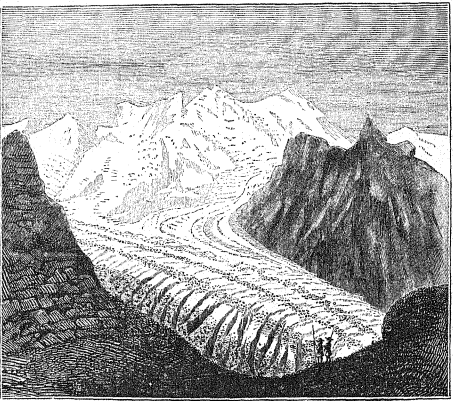
3. Glaciers. — Glaciers are broad and deep streams of ice in the great valleys of snowy mountains like the Alps. The snows that fall about the summits above the level of perpetual snow accumulate over the high region until the depth is one or more hundred feet. At bottom it is packed by the pressure and becomes ice. Its weight causes the ice to descend the slopes of the mountains and along the valleys, which it fills from side to side. The width of the ice of the valley may be several miles; its depth in the Alpine valleys is generally from 200 to 500 feet.

The glaciers descend far below the line of freezing to where the fields are green and gardens flourish; and this takes place because there is so thick a mass of ice. In the Alps the glaciers stretch down the valleys 4,500 to 5,300 feet below the snow-line. At Grindelwald two glaciers terminate within a short distance of the village.

The rate of movement in the Alps in summer is mostly between 10 and 20 inches a day, and half this in winter; 12 inches a day corresponds to a mile in about 14½ years.

Fig. 52 (from a sketch in one of Agassiz's works on glaciers) represents one of these great ice-streams or glaciers descending a valley in the Monta Rosa region of the Alps. A valley often narrows and widens at intervals, and changes its slope at times

Fig. 52.



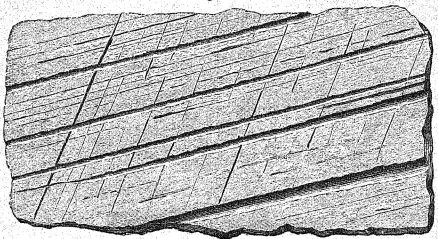
Glacier of Zermatt, or the Görner Glacier.

from a precipitous to a horizontal surface. The ice has to accommodate itself to all these variations. On turning an angle it is broken, or has great numbers of deep "crevasses" made through it, especially on the side opposite the angle. On com-

mencing a rapid descent, great breaks, or crevasses, cross the glacier from one side to the other. On reaching a level place again the ice closes up, and the glacier loses nearly all its crevasses. The ice is brittle, and freezes together when the separated parts are brought in contact again; so that, as it moves, it goes on breaking and mending itself. Ice is plastic; for it may be made into rods by pressing it through a hole, and will take the impress of a medal; so that it can accommodate itself in this way also to the changing character of the surface over which it moves.

Along the sides of the glacier the cliffs of rock often send down stones and earth, or avalanches of ice and rocks; and these make a line of earth and rocks along either margin, which

Fig. 53.

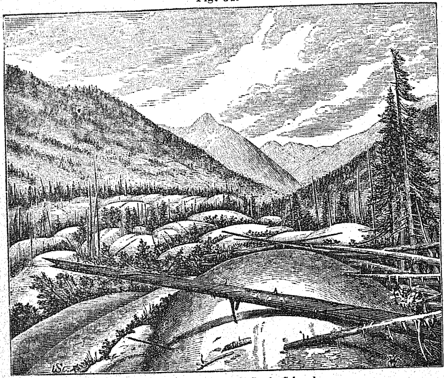


Glacial scratches and planing.

is called a *moraine.* These moraines are carried with the ice to where it melts, and there dropped. Other blocks are taken up by the sides and bottom of the glacier.

Wherever a glacier has moved the rocks are scratched, planed, or polished, often with great perfection, as illustrated in Fig. 53.

Fig. 54.



View on Roche-Moutonnée Creek, Colorado.

Ledges of rocks also are rounded, making what are called sheep-backs, or, in French, *roches moutonnées*. Fig. 54 represents the *roches moutonnées* in a valley of the mountains of Colorado, — a valley leading up to the Mountain of the Holy Cross, seen in the distant part of the view. It is from the Report of Dr. Hayden for 1873. No glaciers exist there now; but once they were of great extent and depth. The

scratching and polishing are done by the stones in the bottom and sides of the glacier; and these stones, as is natural, are also planed off and scratched.

4. Icebergs. — In the Arctic regions the glaciers of Greenland, loaded with their moraines, extend down into the sea, and the part in the water sooner or later breaks off and floats away as an *iceberg*. These icebergs are carried south by the Labrador current, and large numbers of them in the course of a season reach the Banks of Newfoundland. There they find the waters warmer, in consequence of the nearness of the Gulf Stream, and they melt and drop their burden of stones and earth into the waters. It has been suggested that the Banks of Newfoundland owe their existence to the melting and consequent unlading there of icebergs.

It thus appears that ice does geological work (1), in the act of formation, through its expansion; as *glaciers*, (2) by transporting over the land earth and stones and rocks,—some of the rocks as large as ordinary-sized houses,—and dropping them when the ice melts; (3) by tearing apart rocks through its movement wherever there are opened seams into which it can pass; (4) by wearing deeply into the soft rocks over which it may move, and scratching and polishing hard rocks; and, as *floating ice* or *icebergs*, by transporting rocks, stones, and earth from one region to another; and (5) it often makes temporary dams across valleys, that cause great devastation when they give way.

7. The Work of Heat in Rock-making.

The effects here mentioned are the following: —

1. Expansion and contraction from change of temperature.

2. The fusion of rocks, and their ejection through volcanic vents and fissures.

3. Solidification and crystallization of fragmental rocks, through long-continued heat, and the filling of fissures and making of veins.

1. Through Expansion and Contraction.

Owing to the alternation each day of sunlight and darkness, the surfaces of exposed rocks experience an alternate heating and cooling, and therefore alternate expansion and contraction. This cause, which is sufficient to break the solder of soldered metallic roofs on houses, to loosen the cemented blocks of a stone wall, and to give a perceptible movement to high stone towers, tends to start off the grains, and sometimes separates an outer layer from bare rocks, especially when the surface is weathered. As it is in action over the whole surface of the earth, it is an important addition, in a quiet way, to the chemical work of air and moisture, in the making of earth or gravel for the formation of rock deposits; and it has been so ever since the sun first shone upon bare rocks. A foot or two of soil is a protection against this method of degradation.

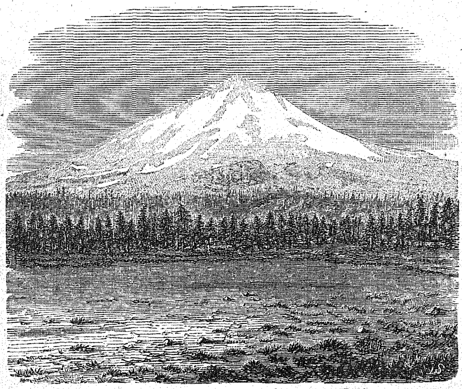
Heat gaining access to rocks beneath a region expands

them and causes an elevation of the surface; and loss of heat produces a reverse effect. Fractures may attend such changes of level, and also light earthquakes.

2. Making of Rocks through Fusion: Volcanoes.

1. Volcanoes. — Igneous rocks, or those made by the cooling of melted rock-material, are described on page 18 as having

Fig. 55.



Mount Shasta, from the north: from a photograph by Watkins.

come to the earth's surface from below through fissures; and also as sometimes having been ejected at intervals from one and the same opening for long periods of time.

When fissures are filled and closed by one eruption, they make *dikes* of igneous rock, and also one or more *beds* if the melted material flows from the fissure over the region adjoining.

But when a vent remains open for many successive eruptions it becomes then the centre of a true *volcano* or fire-mountain. The outflows of liquid rock, and ejections of volcanic sand or cinders from one side and the other around the vent, produce a hill or mountain of a form more or less nearly conical. Fig. 55 represents Mount Shasta, one of the volcanic mountains of Western North America, having an elevation, according to Whitney, of 14,440 feet. It is not now in action, yet has hot springs near its summit. It also represents well the general form of the great volcanoes of the Cascade range to the north of it in Oregon, and of those along the Andes in South America. Of the latter Cotopaxi is an active volcano 19,660 feet in height, and Arequipa another, 18,877 feet, while Aconcagua, of Chili, has a height of 22,478 feet, and is the loftiest peak in the Andes.

Active volcanoes send forth only vapors in their times of quiet. In periods of eruption streams of lava (or liquid rock) are poured out, — either over the edge of the crater or through breaks in the sides of the mountain. The latter is the common mode. At the same time cinders — or fragments of lava — are often thrown from the crater to a great height above the volcano, to fall in showers around.

Volcanoes vary much in angle of slope. When made of cinders the angle is often 40° to 42°. If formed through the alternations of lavas and cinders, or of tufas, the slope may be 30° or less, as in Figs. 55 and 56. Fig. 56 gives the slopes of the volcano of Jorullo, in Mexico. Many of the grandest volcanoes of the world, like Etna, and those of Hawaii, in the Sandwich Islands, have an exceedingly gentle slope, — the height only a twentieth of the breadth, as in Fig. 57, giving the slope of Mount Loa, of Hawaii. These last are made almost solely of lavas; and they have so gentle a slope, because the melted rock of the region flows off freely.

Fig. 56.

The eruptions of volcanoes are owing mainly to the waters that gain access to the fires. The rains of the region produce underground streams that descend and pass into the melted rock, there to be changed to vapor; and sea-water, when volcanoes are near or in the ocean, presses its way in, or gains access suddenly through fractures. The vapor penetrating the liquid mass expands the whole, causing it to rise in the vent. The fires become hotter with the increasing height of the column of melted rock in the mountain, and the vapors more active. The pressure from the high liquid column, and from the vapors, breaks the mountain, and the lavas run out, devas-

Fig. 57.

tating the country, it may be, for a score of miles or more. When the sea gains sudden access to a volcanic vent, the eruption is accompanied with violent quakings of the mountain. Every few years the country on one side or another of Vesuvius is deluged with the fiery rock, cultivated fields buried, and not unfrequently villages destroyed. Pompeii and Herculaneum were buried beneath the cinders of an eruption that took place in the year 79 of our era; and since then several streams of lava have flowed down over Herculaneum, adding to the depth of rock over it. The deposits of cinders make a kind of soft sandstone called tufa.

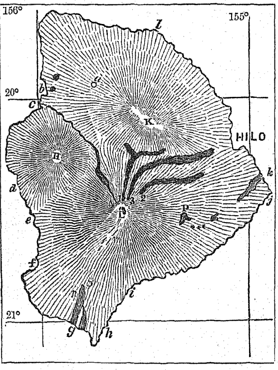
Mount Loa, on Hawaii, has had six great eruptions through fissures in the sides of the mountain within 30 years. There is a summit crater (L on the map) at a height of 13,760 feet, and another called Kilauea (at P), nearly 4,000 feet above the sea, which is the larger of the two. The map shows at 1, 2, 3, 4, 5, and between P and K, the courses of the eruptions. K is the position of another volcanic mountain, Mount Kea, as high as Loa, and H, of another, 10,000 feet high.

The liquid rock comes up from some deep-seated fire-region.

Volcanic mountains are very numerous along the Andes; in Central America and Mexico; in Oregon and Washington Territory, from Mount Shasta to Mount Baker and beyond; in the Alaska archipelago on the north; all along the west side of the Pacific through Japan and the East Indies; southward in the New Hebrides, New Zealand, and in Antarctic regions.

Thus the Pacific, the great ocean of the globe, is girt with volcanoes, besides having many over its surface. The Atlantic, in contrast with it, has none on its borders, except in the Gulf

Fig. 58.



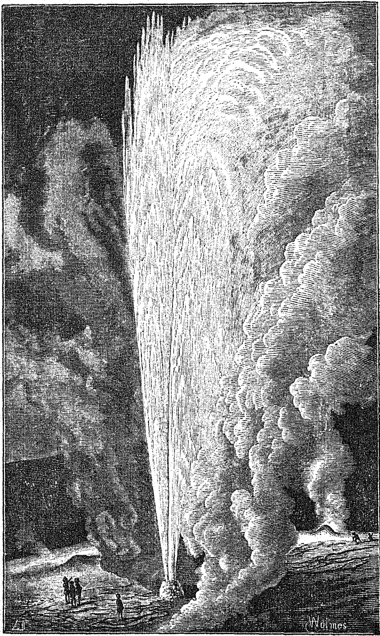
Island of Hawaii.

L, Mount Loa; K, Mount Kea; H, Mount Hualalai; P, Kilauea or Lua-Pélé; 1, Eruption of 1843; 2, of 1852; 3, of 1855; 4, of 1859; *a*, Waimea; *b*, Kawaihae; *c*, Wainanalii; *d*, Kailua; *e*, Kealakekua; *f*, Kaulanamauna; *g*, Kailiki; *h*, Waiohinu; *i*, Honuapo; *j*, Kapoho; *k*, Nanawale; *l*, Waipio; *m*, first appearance of eruption of 1868; *n*, Kahuku. The courses of the currents 1, 2, 3, and 5 are from a map by T. Coan, and 4, from one by A. F. Judd.

of Guinea on the coast of Africa, and in the West Indies; and but few over its interior.

Hot springs often make deposits of silica around them, owing to the silica the heat has enabled the waters to take up from the rocks with which they are in contact. Such

Fig. 59.



Beehive Geyser in action.

springs sometimes throw their waters in jets at longer or

shorter intervals, and they are then called *geysers*. One of the geysers of the Yellowstone Park, in the Rocky Mountains (where there are great numbers of them), is represented in action in Fig. 59, taken from Hayden's Report for 1873. It throws the water to a height of 200 feet or more. The geysers of Yellowstone Park are mostly about the Fire-hole River, a fork of Madison River, and near Shoshone Lake, the head of Snake River, and not far from the head of the Yellowstone. The number of hot springs, hot lakes, and geysers in the Park has been stated to be not less than 10,000.

Solfataras are regions about volcanoes where vapors issue and sulphur is deposited. The name is from the Italian for sulphur.

3. Solidification, Metamorphism, and Formation of Veins.

1. Solidification. — Limestones have been solidified through carbonate of lime (bicarbonate) in solution in waters; also some sandstones by the same means, the lime-salt being derived from the grains of shells, corals, etc., in these rocks. Some sandstones have been partially hardened by the silica in solution in many cold waters, especially where there are diatoms (page 35) in the rock, to enter into solution. The masses of flint and hornstone in rocks are made out of diatoms and other siliceous relics (page 38) by consolidation in cold waters; and many fossils have been turned to quartz (silica) in the same way.

But some of the oldest of sandstones and shales are still

soft or unconsolidated. A large part of the more solid have had the aid of heat in solidification, — heat producing siliceous waters for the work. Hot waters containing in solution some alkali, as soda or potash, have the power of dissolving silica; and they find both the silica and the needed alkali in the feldspar of igneous or other rocks, and hence the waters of hot springs are generally siliceous.

2. Metamorphism. — This heat, when it has been long continued, — probably for thousands of years, — has not only consolidated the rocks, but has also crystallized them, turning sandstones, shales, and conglomerates into the *metamorphic* rocks, granite, gneiss, mica schist, hornblende rock, and other kinds. Those fragmental rocks were made by the pulverizing of granite, gneiss, mica schist, and the related rocks; and hence the return to granite, gneiss, mica schist, and the like by a new crystallization, when acted upon throughout by heat and moisture, is not a matter of surprise.

Moisture at a high temperature has, moreover, great decomposing and recomposing power; and many minerals — as mica, feldspar, hornblende, and others — may be made and crystallized through its action, and thus become constituents of metamorphic deposits when not originally present. The heat of metamorphism was generally much below that of fusion, this being obvious from the fact that the stratification of the rocks is perfectly retained; for the layers of mica schist and gneiss correspond with the bedding of the sandstone or shale out of

which they were made. But, in some cases, the heat was sufficient to soften the rock, and then the planes of stratification were obliterated, making granite instead of gneiss, — granite differing from gneiss only in the absence of anything like stratification or an arrangement of the material in layers. There are all shades of gradation between granite and gneiss.

Heat has changed common or compact limestones, that were gray to black in color and full of fossils, into white or clouded crystalline limestones, that is, white or clouded marbles. In a case of this kind the metamorphism may have consisted simply in crystallization. Yet at the same time the impurities of the limestone have sometimes been converted by the process into grains of mica and other minerals, which are distributed through the rock. Similarly other rocks, like mica schist, gneiss, etc., have been filled with various crystallized minerals, as garnet, tourmaline, staurolite; and even the gems, sapphire, ruby, topaz, and the diamond are among the results of the metamorphic process. Moreover, beds of earthy iron-ores have been made into crystalline iron-ores, examples of which on a grand scale occur in the Adirondack region of Northern New York, the Marquette region in Michigan, and in the Iron Mountains of Missouri.

Metamorphism has been carried on at once over regions thousands of square miles in area. The rocks undergoing the change were undergoing also an upturning and fracturing on a scale as extensive; and the movements were the source of

the heat that caused the metamorphism, just as the rubbing of two sticks together produces heat. The upturned ore-beds often look like *veins* of ore, and are sometimes wrongly so called.

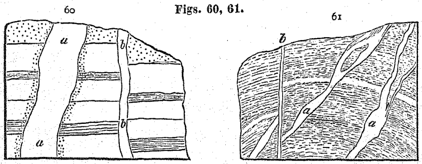
Hot springs occasionally produce metamorphism in the rocks about them, besides causing ordinary consolidation. The waters of geysers (page 68) deposit a large amount of silica in the form of opal, making opal basins for themselves to play in, and spreading the opal widely over the region around. They also produce the petrifaction of wood, changing the trunk of a tree into silica, and generally without obliterating the grain or structure of the wood. But the making of such petrifactions does not demand heat, as they have often been produced in beds of earthy or calcareous mud when siliceous infusoria were abundant in it, as stated on page 70.

The opal of geyser regions is of a coarse kind, yet is often beautiful in its forms about the pools. The precious opal has been mostly produced in feldspathic lavas (trachytes) that have been long subjected to hot waters, and which, under the action, have yielded up part of their silica to deposit it again as opal in the cavities of the rock.

3. Veins. — Rocks have often been extensively broken so as to be intersected by great numbers of fissures large and small; and in upturnings the layers, especially of shaly rocks, have been opened, as the leaves of a quire of paper are separated more or less on bending it into an arch. The fissures, in

such cases, and all the openings, have become filled while metamorphic changes were in progress, by crystallized rock-material, derived from the rock either side of the fracture or from depths below; and metallic ores of various kinds, as of lead, silver, and copper, and also native gold, have often been carried into the openings or fissures along with the rock-material. Veins (Figs. 60, 61) are the fillings of fissures, and this is the most common way in which they have been made. The mate-

Figs. 60, 61.



Rocks intersected by veins, *a*, *b*.

rial is carried in, from the rocks on either side or below, by the moisture present, this, at the high temperature, dissolving it; and thus laden it has pressed into all opened spaces, there to deposit it as long as there was open space to be filled. Such veins, and the seams occupying openings between layers, afford a large part of the metals of the world, iron excluded. Gold is found in such veins, or else in the gravel made out of gold-bearing rocks by some process of wear or destruction.

Many veins consist of quartz alone (such are most gold-bearing veins); others of coarse granite, and of various other

kinds of rock-material. They are frequently *banded*, that is, are made up of layers parallel to the walls. These layers consist of different kinds of minerals and ores: there may be an outer layer of quartz; next one of ore; then another of quartz, or of calcite, or of some other earthy mineral; then perhaps another of ore. Such a structure is proof that the vein was filled by deposition against the walls, one layer after another, and that they were not made by injection of liquid rock from below.

Other metallic veins have been made in connection with igneous ejections. Fissures have opened down to regions of liquid rock, and sometimes ores have ascended along with the liquid rock; but often, in some part of the same disturbed region, other fissures have opened which have received from below only vapors or solutions of mineral matter including the ores. The waters that exist as subterranean streams, especially beneath stratified rocks, have frequently made their way into such opened fissures, and there becoming at once highly heated, have aided in carrying the material upward, and also in determining its condition and its arrangement in the veins.

In Fig. 61 the vein *a* is broken off and displaced — that is, *faulted* — along the line of the vein *b*. When the fissure occupied by the vein *b* was opened the rock of one side slipped by, or was shoved by, that of the other side, and so the *fault* or displacement was made. Such faults are very common.

II.—Making of Valleys.

Valleys are made (1) by *erosion* by the streams of the land,—the common way; (2) by *upliftings* or *flexures* of rocks making mountains and leaving troughs or low regions between the mountains as valleys; (3) through *fractures* of the earth's crust.

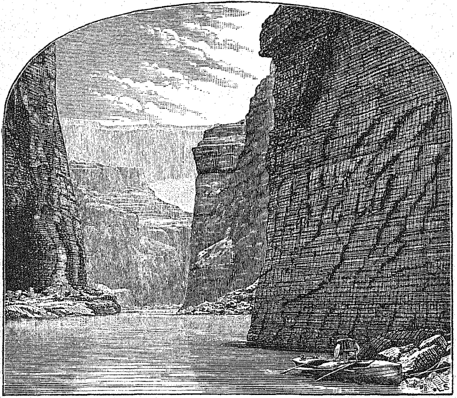
1. Valleys of erosion.—Slopes of sand or gravel are sometimes deeply gullied by the heavy rains of a single day, or, in geological language, deeply *eroded*, or eaten out as this word means. This work of the rains often gives a very exact model, on a small scale, of the valleys and ridges of mountain regions. The gully, or little valley, has often (1) a precipice at its head; (2) little waterfalls along the steep part of its course, wherever there was a harder layer of sand; (3) a narrow bottom with steeply sloped sides; but, near the foot of the hill, where the surface is nearly horizontal, a broad and flat bottom of sand laid down by the spreading waters. And the ridgelets between the little valleys have often a broken, knife-edge summit in their upper part, and are broader below. The reader should study carefully the first gullied slope of this kind that he may meet with, for it will be a study of valley-making over the world. Only a single night's rain may have sufficed to make the little valleys and ridgelets of the sand slope, because the sand was not firmly consolidated. But

if the rocks be ever so hard they yield in the same way, and with time enough, the same forms, on the scale of the grandest mountain region of the world, have resulted. Many of the river-valleys of North America, and of other continents, illustrate this action of running water. Watkin's Glen, near Ithaca, Trenton and Niagara Falls, in Central and Western New York, and the Valley of the Upper Mississippi, afford examples.

The character of the valleys and ridges will depend much on the hardness, structure, and position of the rocks. When the beds are nearly horizontal, precipices and waterfalls are most common.

The Colorado River of Western North America runs for two hundred miles through a gorge or cañon with vertical walls of rock in many places over 3,000 feet high. The sketch in Fig. 62, from a photograph obtained by Powell's expedition, is a view of a portion of this cañon between the Paria and the mouth of Little Colorado, called Marble cañon. The walls in the distant part of the view have a height of 3,500 feet, and consist of limestone, whence its name. But in other parts of the Colorado cañon there are various kinds of strata, and in some places the cut has been made deep into the underlying granite, — and all is the work of the river. The waters have a rapid and often plunging flow, owing to the slope, and carry along pebbles and stones, and these stones aid greatly in the erosion. But to wear out so wide and deep a channel a long period of

Fig. 62.



Marble Cañon, on the Colorado.

time was required. Above the gorge, some miles back from the river, the horizontal rocks are piled up to a still greater height, reaching in some places a level 8,500 feet above that of the bed of the stream; and these piles of strata standing in separate ridges, sometimes in the form of pinnacles, castellated structures, and table-topped mountains, are parts of great rock-formations that once spread across the wide region. They show that erosion has carried away the larger portion of these upper rocks, the mountains and pinnacles being merely remnants of them.

The ocean may have aided in the removal when the land stood at a lower level, partly submerged; but it could not have cut out the gorge or cañon; for the work of the ocean is to wear off headlands, form sand-flats or beaches along coasts, and fill up bays, not to cut channels into a coast and make deep valleys. The ocean has done but little valley-making, and only that of the broadest kind, when its wide currents swept over the submerged continent. The gorging of mountains and plains it has left to the running waters of the land. These running waters have been aided in some cases by glacier-ice (page 58).

2. Valleys made by the upheaval of mountains. — The wide Mississippi valley is a depression between the Rocky Mountains on the west and the Appalachians on the east. The making of these mountains was the making of the valley. The Connecticut and Hudson Rivers occupy depressions that were probably made by uplifts either side of them. The Adirondacks are among the oldest of mountains. Long after these the Green Mountains were made; and when raised, the valley in which lies Lake Champlain was a region left low at the time. Again, the valley of the Sacramento originated in the making of the Sierra Nevada on one side, and, later, the Coast ranges on the other. The other continents afford similar examples.

8. Valleys made by fractures of the earth's crust. — 1. A great fissure in a volcanic mountain opened for the ejection

of lavas has sometimes been left, after the eruption ceased, as a deep valley. 2. Great regions have subsided in consequence of subterranean movements, leaving valley-like depressions. 3. Profound fractures have taken place in connection with mountain-making, leaving sometimes open rents, as narrow valleys or gorges.

But, notwithstanding the frequency of fractures, there are few valleys over the earth that can be pointed to as made in this way. Fractures have sometimes determined the courses of streams; but the stream, thus guided in its original course, has afterward carried forward its work of erosion, and made the great valley in which it flows.

III.—Making of Hills and Mountains, and the attendant effects.

THERE are three prominent methods of mountain-making, producing widely different results.

1. Mountains made by Igneous Ejections.

Mountains have been made by igneous ejections, especially by those of volcanic vents, as explained on page 64. Thousands of square miles over the western slope of the Rocky Mountains have been covered by igneous rocks, and in Oregon they have a thickness of more than 4,000 feet; and, besides, they form cones there, whose summits are 10,000 to 14,440

feet above the sea. The loftiest peak of the Andes, nearly 23,000 feet high, as already stated, and numerous others in that chain, were made by volcanic action. Mount Etna, in Sicily, is nearly 11,000 feet high; two volcanic mountains of Hawaii are nearly 14,000 feet high, and another is about 10,000.

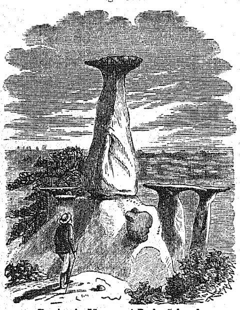
This is the least important of the methods by which mountains have been formed.

2. Mountains and Hills produced by the Erosion of Elevated Lands.

In all mountain regions the lofty summits and ridges have been shaped out mainly, as already explained, by running water, and such heights are therefore examples of the results of erosion on elevated lands. But the mountain-making is a little more completely the work of erosion when a region of horizontal rocks, which when first raised was a lofty plateau, has undergone long erosion. Owing to the height, perhaps several thousand feet, the torrents which the rains make and feed have a steep descent, and therefore great eroding power; and ultimately such a plateau has often been reduced to a region of profound valleys and precipitous ridges. The elevations described on page 78, as the remnants of a great rock-formation, are examples of mountain sculpture of this kind. These remains are battlemented heights, temples of mountain-dimensions, towers, and columns. The elevations have often a broad cap of harder rock at top, and if of much breadth they are

called *mesas,* from the Spanish *mesa,* a *table.* The Catskills are a group of high summits 3,000 to 4,000 feet above the sea-level, carved by running water out of an elevated region of nearly horizontal rocks. Such examples are very common over the world. For in the changes of level which the earth's crust has undergone areas have often been lifted without much disturbance of the beds.

Fig. 63.



Erosion in Monument Park, Colorado.

Examples of monumental forms on a small scale occur in Colorado, and have given the name of Monument Park to the region. Fig. 63 is a sketch of a scene in it, from Hayden's Report for 1873. Such effects of erosion may have been produced mainly by rains and running water; but they are in part due to the winds; to the quiet work, chemical in nature, of air and moisture; to the alternate heating and cooling of the surface in consequence of the daily changes of temperature; and, in frosty regions, or where the winters are cold, to the freezing of moisture over the surface.

Over undisturbed regions of Tertiary and Quaternary for-

mations erosion has often reduced the once level surface to a collection of hills. In some parts of the eastern slope and summit of the Rocky Mountain region the Tertiary is worn into a labyrinth of valleys and variously shaped ridges, needles, and table-like elevations.

This mountain-making by erosion is an external sculpturing of the earth's surface, and not true mountain-making, — the subject considered under the third head.

3. Mountains made by Upturnings and Flexures of Rocks, and Bendings of the Earth's Crust.

Mountain ranges have been made, for the most part, through bendings of the earth's crust, and the upturning and flexures of the rocks.

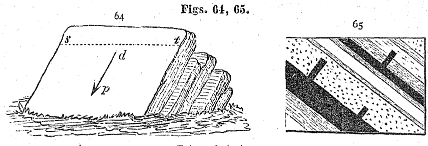
1. Upturned rocks. — The layers of stratified rocks were, with small exceptions, originally horizontal, this being the position which layers of sediment usually have when forming. They are now very commonly more or less upturned. Sometimes the angle of inclination is small; but in most mountain regions the beds are inclined at high angles, and often are vertical or nearly so. In the study of the inclined positions of strata the geologist studies the origin of mountains.

The inclination of the beds below a horizontal plane is called the *dip;* and the horizontal direction at right angles to the *dip* is the *strike.* When the roof of a house slopes in opposite directions from a horizontal ridge-pole, the angle of slope

or pitch of the roof corresponds to the *dip;* and the direction of the ridge-pole, to the *strike.*

Some of the positions of upturned rocks are shown in the following figures. Fig. 64 represents a ledge of rocks pro-

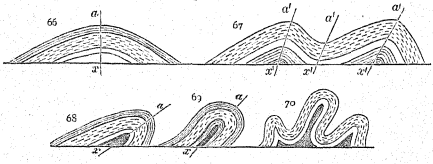
Figs. 64, 65.



Upturned strata.

jecting above the ground; *d p* is the direction of the *dip,* and *s t* that of the *strike.* Fig. 65 represents a portion of the coal-formation with stumps of trees rising out of the coal-beds, which have lost their vertical position because of the upturning of the strata.

Figs. 66 – 70.

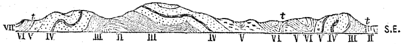


Flexed or folded strata.

2. Flexures. — Figs. 66 – 70 represent flexures or folds of the strata, — such as are of common occurrence. The folds

in a mountain region are sometimes many miles in span, and often one arch rises beyond another. The Appalachians and Jura Mountains are full of examples. The upward bend (at *a x* in Figs. 66–69) is called an *anticlinal*, from the Greek signifying *inclined in opposite directions;* and the downward bend (at *a′ x′*) a *synclinal*, meaning *inclined together*. *a x*, *a′ x′* are the positions of the *axes* or *axial planes* of the folds, *a x* an *anticlinal axis* and *a′ x′* a *synclinal axis*. In Figs. 68, 69 the folds are pressed over beyond a vertical, so that the axial plane makes a large angle with a vertical line. In Fig. 70 three folds are raised together.

Fig. 71.



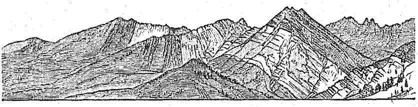
Section from the Great North to the Little North Mountain, through Bore Springs.
t t, positions of thermal springs.

Fig. 71 represents an actual section six miles long, from a part of the Appalachians illustrating well the flexures. But it illustrates another fact: that, since the flexures were made, the region has been worn by waters, either those of rivers or the ocean, so that the tops of the flexures are worn off, and where they once were there are now valleys; such a valley is represented in Fig. 71, to the left of the middle above II. The tops of such folds would have been broken deeply while the bending was in progress, and the breaks would have opened upward; and therefore these should be the parts most deeply eroded. The thin black layer over IV, on the left,

was once continuous with IV, near the middle of the section; and so with the rest. To the right end of the section the beds are vertical.

Another view of upturned and eroded rocks as they occur at a locality in Western Colorado is given in Fig. 72. The

Fig. 72.



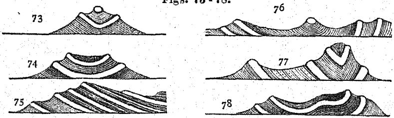
Upturned strata of the west slope of the Elk Mountains, Colorado.

The light-shaded stratum, Triassico-Jurassic; that to the right of it, Carboniferous; that to the left, Cretaceous.

strata in the foreground have the reverse dip of those more distant, showing a twist connected with the upturning.

Other examples of folding and of subsequent degradation, from the Alleghanies, are illustrated in Figs. 73–78. In

Figs. 73 - 78.



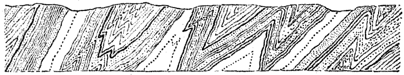
Degradation of a folded mountain region.

each case the harder stratum in the series determines in a large degree the final form of the hill and the landscape effect of the erosion.

Fig. 79 represents a still more remarkable case of flexures

and subsequent erosion; the folded region has been worn away to a nearly level surface, so that the existence of flexures is to be ascertained only in vertical sections of the rocks. Regions of such folded rocks are generally very difficult to study, because of the extensive erosion. Ledges and ridges in which the strata slope only in one direction are often one side or part of a great fold.

Fig. 79.

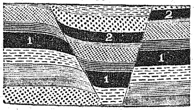


General view of folds in the Archæan rocks of Canada.

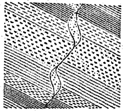
3. Fractures and Faults. — Besides flexures, great and small *fractures* have been made during epochs of upturning or mountain-making. Fig. 80 represents strata thus broken; and, moreover, the beds are displaced along the fractures. The beds numbered 1, 1, 1 were once a single continuous layer;

Figs. 80, 81.

80



81



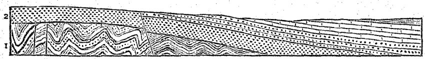
Fractures and Faults.

and so with the others; but at the time of fracture there was a dropping of the middle portion, so that along each fracture there is now a *fault*, or displacement. Another case is illus-

trated in Fig. 81. The fault in a vein described on page 75 is another example. The figures represent faults or displacements of only a few feet or yards; but in many faults, produced in the making of a range of mountains, the rocks of one side of a fracture have been pushed up, or have dropped down, thousands of feet. When fractures are very numerous over a region, and of great extent and regularity, they are called *joints*.

4. **Unconformable strata.** — Rocks are often laid down horizontally over upturned rocks; the layers of the two do not then *conform* to one another; as in Fig. 82, in which the

Fig. 82.



Section from south side of the St. Lawrence, Canada, between Cascade Point and St. Louis Rapids.
1, gneiss; 2, Potsdam sandstone.

rocks 1 and 2 are *unconformable,* while 2 and those overlying 2 are conformable. In the figure there is a *fault* represented to the left of the middle; and there are others farther to the left, which are confined to the lower beds (1), and which, therefore, were made before the next stratum above (2) was deposited.

5. **Earthquakes.** — The upturning, flexing, and fracturing of rocks could not have taken place on so grand a scale without sudden shakings or jars of the rocky strata; and every such jar was an *earthquake.* A scratch of a pin on the end of a

log may be heard by placing the ear at the other end, because the vibration made by the scratch travels along the log, and with great rapidity. A jar in the earth's crust or its rocks travels in the same way. It has often, in modern times, been felt through a hemisphere. Subterranean thunder has been a consequence of it; and profound fractures of the earth's surface, resulting sometimes in the destruction of cities and human lives. Earthquakes occur whenever there is any yielding or slipping or fracture of the rocks beneath the earth's surface; and they are most likely to occur along the mountain border of a continent where have been the greatest upturnings, and especially where there are volcanoes along such borders.

6. Metamorphism. — The upturning, fracturing, and flexing attending mountain-making accounts for the heat required for *metamorphism*, and for the very wide extent of most areas of metamorphic change; for regions of metamorphism are regions of upturned rocks (page 72).

7. Cause of upliftings, fractures, and flexures, and of mountain-making. — If a quire of paper, lying on a table, be pressed together at the front and back edges, it will rise into a fold; and, in case the paper is a soft and inelastic kind, into a series of folds. Pushing from below will make it bulge upward, but only *lateral* pressure will make a succession of folds. The facts with regard to flexures in the rocks of mountain regions prove that the force which has made the great

series of folds, uplifts, and fractures has acted *laterally;* that is, it was *lateral pressure within the earth's crust.*

Mountain ranges occur on all the continents, showing that the cause of uplift and flexure has been a universal one; and so lateral pressure within the earth's crust is a force necessarily universal in its action. Mountain ranges are hundreds and even thousands of miles in length; and a cause thus universal is sufficient to have made all, whatever their length or height.

This lateral pressure is attributed to the admitted fact that the earth was once melted throughout, and has gradually cooled over its surface; and that the first crust formed has been thickening below from the continued cooling. In cooling from fusion a rock contracts, losing on an average a twelfth of its bulk; and hence continued cooling means continued contraction beneath the first-formed crust, and an effort to draw it downward. The crust would be necessarily put, under such circumstances, into a state of pressure of every part against every adjoining part, like the pressure between the stones of an arch; and if any part gave way, or the crust were flexible at all, there would be uplifts, flexures, breaks, or faults. The flexures in the earth's strata are, then, the effects of this lateral pressure, and are some evidence as to its extent and power.

The great ranges of mountains are situated, for the most part, on the borders of the oceans. Thus on the Atlantic

border there is the Appalachian chain, while on the Pacific stand the lofty Rocky Mountains. Again, in South America there are the Brazilian Mountains on the east, and the far greater chain of the Andes on the west. Other continents illustrate the same truth, — that the continents have high borders and a low interior, and also that the highest border faces the larger ocean.

Moreover, the volcanoes of the continents are, with few exceptions, near the ocean, and far the greater part of them are on the borders of the Pacific or larger ocean (page 67).

These facts prove that the breaks and uplifts that were made by lateral pressure in the earth's crust were mostly confined to the borders of the oceans, and that they were most extensive on the sides of the largest ocean.

A reason for this position of the great mountain chains near the oceans is found in the fact that the crust of the earth that lies beneath the ocean's bed is lower in level than that of the land, and the basin-like depression has rather abrupt sides toward the continents. Owing to this the action of the lateral pressure from the direction of the ocean was *obliquely upward* against the land, and therefore just what was required to push *up* the borders of the continents into mountains, or to produce flexure after flexure in the yielding rocks, or to break them and give outflow to floods of lava.

Mountain chains are the result of more than one mountain-making process. A single example will suffice to illus-

trate this truth. The range of elevated land from Labrador to Alabama is called the Appalachian chain. But the Adirondacks, the Highlands of New Jersey, and portions of the Blue Ridge of Pennsylvania and Virginia were made long before the rest. The Green Mountains *east* of the Adirondacks were next raised; then, after another immense period of time had passed, at the close of the Carboniferous age, the Alleghanies from New York to Alabama, *west* of the line of the Blue Ridge and Highlands, were completed. Thus the Appalachian chain was a result of a succession of mountain-making efforts, one producing one part, and the rest others. The process did not go on twice along just the same range of country, but to one side of the preceding, either east or west. Since the completion, the country has been raised as a whole by a gentle bending upward of the earth's crust, — the lateral pressure in this case, after the mountains were made, and their rocks folded and consolidated, and the crust thereby stiffened, producing a slight flexure of the crust and not any folding of strata.

After the making of the Alleghanies there was mountain-making of a different kind more to the eastward in the course of the next age. Along the regions of the Bay of Fundy, the Connecticut Valley south of New Hampshire, and a long range of country from the Palisades on the Hudson through New Jersey and Pennsylvania into North Carolina (each region parallel to the part of the Appalachian chain west

of it), where several thousand feet of sandstone had been deposited, there were made, finally, along with a small upturning of the strata, a vast number of great fractures of the earth's crust, the fractures deep enough to let out melted rock; and this rock, cooled, constitutes the Palisades on the Hudson, Mount Holyoke in Massachusetts, and various other trap ridges in the Connecticut Valley, Nova Scotia, and the more southern sandstone regions. Here the lateral pressure produced little upturning, but much fracturing, with extensive igneous ejections; and this exemplifies a second method of action in mountain-making, a method which was most common in the later end of geological time, when the earth's crust had become too stiff to bend easily. After this epoch of disturbance there were no other general upturnings along the Atlantic border of the continent. Mountain-making was there ended long before it was on the Pacific or Rocky Mountain side, and long before it was in Europe. Neither these mountains nor the Alps, Pyrenees, or Himalayas were finished before the close of the Tertiary; and the grandest of igneous ejections in the world belong to the same age, the last before Man.

Another principle connected with mountain-making remains for consideration. It will be best understood after some of the facts in geological history have been reviewed; the discussion of it is therefore deferred to the pages treating of the formation of the Alleghany Mountains. (See pages 171, 208.)

7. Making of continents and the oceanic depression. — Contraction from cooling also gives a reason for the existence of the great depressions occupied by the oceans; for, on this view, they are the parts of the earth's crust that have sunk most with the progressing contraction, — the parts, therefore, which were last stiffened, when the crust was in process of formation; while the continents were the portion that contracted least, or which first became solid.

8. Conclusion. — There is thus, in the single fact that the earth is, and ever has been, a cooling globe, and therefore universally a contracting globe, an explanation (1) of the gentle oscillations of level in the earth's surface that have been quietly going on through all past time; (2) of the upturnings, flexures, fractures, faults, and upliftings of strata, and the bendings of the earth's crust, which have resulted in the making of the great mountain chains of the globe; (3) of the opening of fractures down to the deep-seated regions of fire giving exit to floods of liquid rock and producing volcanoes; (4) of the alteration of rocks, or their metamorphism, changing the rude sand-beds and mud-beds into crystalline rocks, and filling fissures with veins of ores and gems; (5) of earthquakes, the great earthquakes and the larger part of the smaller ones; and, finally, (6) an explanation of the origin of continents.

It may be thought that by thus referring to secondary causes the making and crystallizing of rocks, the placing and raising of mountain chains, and even the defining of continents, we

leave little for the Deity to do. On the contrary, we leave all to him. There is no secondary cause in action which is not by his appointment and for his purpose, no power in the material universe but his will. Man's body is, for each of us, a growth; but God's will and wisdom are manifested in all its development. The world has by gradual steps reached its present perfected state, suited in every respect to man's needs and happiness, — as much so as his body; and it shows throughout the same Divine purpose, guiding all things toward the one chief end, — Man's material and spiritual good.

PART III.

HISTORICAL GEOLOGY.

Subjects and Subdivisions.

HISTORICAL GEOLOGY treats of, —

1. The succession in the formation of the rocks of the earth, and in the conditions under which they were made.

2. The progress in the continents, from their small beginnings to their present magnitude.

3. The changes of level ever going on, and the raising of mountains at long intervals in the course of the ages, the highest and longest in the last of those ages just before the era of Man.

4. The multiplication of rivers as the dry land extended, and thereby the excavation of valleys, the shaping of lofty ridges giving grandeur to the mountains, and the spreading of the lower lands with soil and fertility.

5. The changes in climate, from the universal warmth of the Archæan world to the existing variety of heat and cold.

6. The succession in the species under the two kingdoms

of life — Plants and Animals — from the simpler forms of early time to Man.

The rocks are sometimes spoken of as the *leaves* of the geological record. But these rocks are in various lands, here some and there others; and how can they be brought into order so as to make a continuous history worthy of confidence? The case would have been hopeless were it not for one branch of this history, — that relating to the *progress of life*. There has been, as above intimated, a succession in the species of plants and animals that have lived upon the globe. The earliest kinds were followed by others, and these by still others, and so on, through age after age, before the final appearance of Man. The plants and animals that lived in the successive periods left their relics — that is, stems or leaves, shells, corals, bones, and the like — in the mud or sand of the sea-bottom, sea-shore flats and beaches, and in other deposits of the era; and these sand-beds and mud-beds are now the rocks of those periods. Hence in the rocks of one era we find different relics, or fossils, from those of the preceding or following era. Geologists have ascertained the kinds that belong to the successive rocks, or eras, of the world; so that, if they come upon an unknown rock with fossils, in a country not before studied, it is only necessary to compare the fossils found with the lists already made out.

For a very long part of early time after life was abundant there were no fishes in the world. The discovery of a fossil

fish in a bed of rock is, hence, evidence that the bed does not belong to the formations of that early time, but to one of some later period. After the first appearance of fishes the kinds changed with the progress of time; so that if, in the case of our discovery, we can ascertain the tribe to which the fossil fish we have obtained belonged, we can then decide approximately the age of the rock which afforded it. No herring, cod, and salmon are known to have existed until near the last of the geological ages; and if the species turned out to be related to these, we should conclude that the rock was among the later in geological history; and a determination of the species might lead to the precise epoch to which it pertained. Bones of beasts of prey, cattle, and horses are found only in rocks of the last two geological ages.

Thus, owing to the succession of life on the globe, the geologist is enabled to arrange the fossiliferous rocks in the order of their formation, — that is, the order of time.

If a stratum in one region contains no fossils, or if its fossils have been obliterated by heat producing metamorphism, the stratum is traced by the geologist to another region, with the hope of there discovering fossils, or at least of finding them in an underlying or overlying stratum. In this and other ways doubts are gradually removed, and the true succession in any region is made out.

The history has thereby been divided into four grand sections: —

I. Archæan Time; that is, *beginning* time; the word *Archæan* is from the Greek for *beginning*.

II. Paleozoic Time, or the era of the *ancient* forms of life; *Paleozoic* being from the Greek for *ancient* and *life*.

III. Mesozoic Time, or the era of *mediæval* forms of life; *Mesozoic*, from the Greek, signifying *middle* and *life*.

IV. Cenozoic Time, or the era of the *more recent* forms of life; *Cenozoic* signifying *recent* and *life*.

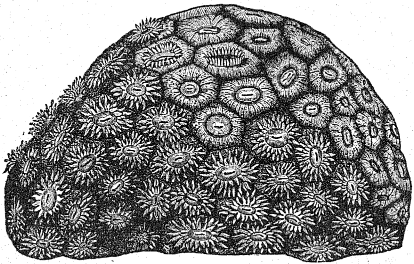
Paleozoic time, which was probably at least threefold longer than all later time, has been divided into three ages: (1) the Silurian, or Age of Invertebrates; (2) the Devonian, or Age of Fishes; and (3) the Carboniferous, or Age of Coal Plants. Mesozoic time corresponds to the Age of Reptiles. Cenozoic time is divided into two ages, called (1) the Tertiary, or Age of Mammals; and (2) the Quaternary, or Age of Man.

The kingdom of Animals has five great branches, or subdivisions, called *sub-kingdoms*. These are,—

1. Protozoans: Microscopic species, with no internal organ beyond a stomach, and none external unless hair-like or thread-like appendages. The Rhizopods and Sponges, of which figures are given on pages 33, 39, are here included. Sponges are large, but only because each is an aggregate of a great number of the minute animals. The word Protozoan, from the Greek, means *first* or *simplest animal*.

2. Radiates: Animals having a *radiated* structure, that is,

Fig. 83.



Astræa pallida D.

having the parts arranged radiately around a centre, with the mouth at or near the centre: as in polyps, the animals of corals, which look very much like flowers on account of the radiate arrangement. Each one of the expanded polyps in this figure of a living coral (Fig. 83) shows well the *radiate* character. The Crinoids, represented on page 31, are other examples of Radiate animals.

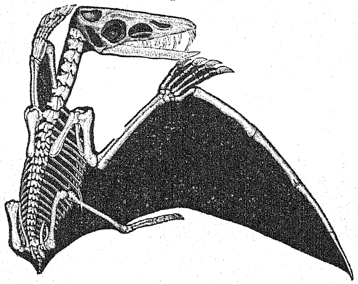
3. Mollusks: as the Oyster, Clam, Snail, and Cuttle-fish; having a soft, fleshy, bag-like body, with sometimes an external shell for its protection, or an internal bone or shell to give a degree of firmness to the fleshy body.

4. Articulates: as the Fly, Butterfly, Beetle, and other insects, the Spiders and Centipedes, the Lobster, Crab, and other Crustaceans, and the Worms: animals having the body made

up of segments or parts jointed together, and having the legs and feelers jointed. A lobster shows well the jointing of the body and of all its limbs. *Articulate* means *jointed.* The Lobster, Shrimp, Crab, and some other related animals are called *Crustaceans* because they have a *crust-like* exterior sometimes called the shell.

5. Vertebrates: as Fishes; Frogs, Lizards, Snakes, Crocodiles, Turtles, and other Reptiles; Birds; the Dog, Cat,

Fig. 84.



Vertebrate.
Pterodactylus crassirostris (× ½).

Horse, Ox, Whale, and other Mammals; animals having internally, along the back, a series of bones making together the *vertebral column.* In Fig. 84, representing one of the Flying Reptiles of ancient time, the vertebral column is seen extending from the head into the tail. Each separate bone

of the column is called (from the Latin) a *vertebra*. The great nerve of the body, called the spinal cord, lies concealed in a tubular bone-sheathed cavity along the upper side of the column; and below the column there are the ribs and the cavity for the stomach and other viscera. The *Mammals* are those Vertebrates that *suckle their young*, as the word, from the Latin, implies. They are the highest of Vertebrates, and include Man as well as the other animals above mentioned.

Protozoans, Radiates, Mollusks, and Articulates are often together called *Invertebrates*, that is, *not Vertebrates*.

In the table above (page 99), the expressions *Age of Invertebrates, Age of Fishes, Age of Reptiles, Age of Mammals*, are not to be understood as implying that the several groups of animals mentioned were confined to the age named after them, but only that they were the highest, and therefore the characteristic, species of the age.

Fishes began before the Silurian Age was quite completed, and continued thence through geological time; but until the close of the Devonian, or nearly so, they were the highest of living species.

In the Silurian, until near its close, there were only Invertebrates.

In the Age of Reptiles, the class of Reptiles, which began in the preceding age, had larger, more numerous, and higher species than before or afterward; the Age was eminently the Age of Reptiles, the type having reached its maximum then, that is, having *culminated*.

Mammals of a low order, called Marsupials, existed in the Age of Reptiles; but in the Age of Mammals the Reptiles were comparatively few, and true Mammals were the highest or dominant race.

Again, the Age of Coal-plants was not the only age in which coal-plants lived and coal was made; but that which was most remarkable for the making of coal-beds, and especially for coal-making plants of the tribe of *Acrogens*, the highest of Cryptogams or Flowerless plants, such as Ferns, Ground-Pines or Lycopods, and Horse-tails or Equiseta, which then grew to the size of tall shrubbery and forest-trees. In later ages also coal-beds were made, but of less extent, and mainly out of other kinds of plants. The Carboniferous age is often called the *Age of Acrogens.*

Thus the Ages are named after the tribes of each, that were highest in grade, or those that were most characteristic.

During an age changes of level, or catastrophes of some other kind, have at intervals produced extensive exterminations of species over a continental sea, and also abrupt changes in the kinds of rock-deposits in progress, if not also upturnings of strata. Each age in the geological history of any continent has consequently its natural subdivisions, which are called *periods.*

The following table gives a general view of the successive ages, with some of the subdivisions that have been adopted, the first in time being at the bottom.

	Ages.		American. Subdivisions.	British. Subdivisions.
CENOZOIC	2. Quaternary		3. Recent.	Recent.
			2. Champlain.	Champlain.
			1. Glacial.	Glacial.
	1. Tertiary		3. Pliocene.	Pliocene.
			2. Miocene.	Miocene.
			1. Eocene, including	
			2. Alabama group.	Eocene.
			1. Lignitic group.	
MESOZOIC	Reptilian		3. Cretaceous.	Cretaceous.
			2. Jurassic	Jurassic, including
				3. Wealden.
				2. Oölyte.
				1. Lias.
			1. Triassic.	Triassic.
PALEOZOIC	3. Carboniferous		3. Permian.	Permian.
			2. Carboniferous.	Carboniferous.
			1. Subcarboniferous.	Mountain limestone.
	2. Devonian		4. Catskill.	Old red sandstone.
			3. Portage and Chemung.	
			2. Hamilton.	
			1. Corniferous.	
	1. Silurian.	Upper.	4. Oriskany.	Ludlow group.
			3. Lower Helderberg.	
			2. Salina.	Wenlock group.
			1. Niagara.	
		Lower.	3. Trenton.	Llandeilo and Bala groups.
			2. Canadian.	Tremadoc and Skiddaw slates.
			1. Prim'l or Camb'n.	Primordial or Cambrian.
ARCHÆAN.				

The accompanying map (Fig. 85) shows the positions of the rocks of the successive ages over part of North America, so far as they are open to view. The markings indicating the age of the rocks of the several areas are explained on the map. The black areas are the great coal areas of the continent. The portions left in white are those the age of which is not ascertained.

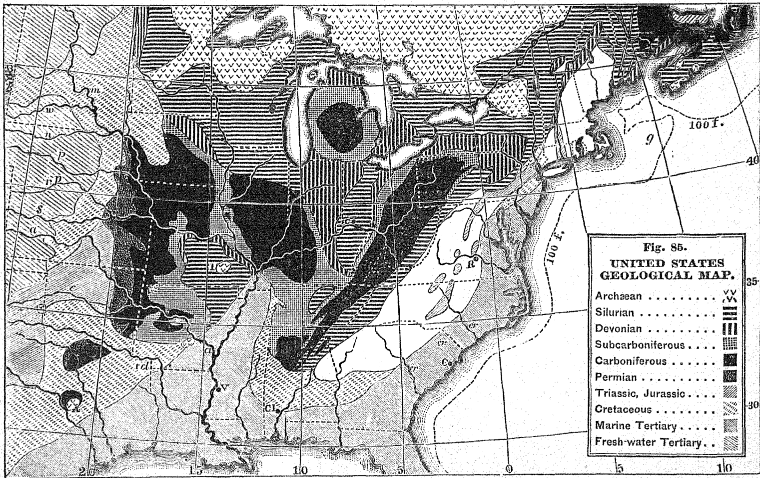


Fig. 85.
UNITED STATES
GEOLOGICAL MAP.
Archaean
Silurian
Devonian
Subcarboniferous
Carboniferous
Permian
Triassic, Jurassic
Cretaceous
Marine Tertiary
Fresh-water Tertiary
100 f.
100 f.
40
35
30
20
15
10
5
0
5
10
V
Cl.
R
C

I.—Archæan Time.

THE first condition of the earth about which geology gives any hint is that of a liquid globe, like the sun. The earth has the form of a sphere flattened at the poles, and as the amount of flattening is closely that which such a liquid globe would take as a consequence of its revolution, this fact is thought to be evidence of an original liquid state. Other evidence is found in the crystalline character of the oldest rocks; in the fact that many spheres in space, like the sun, are still in a liquid state; and in the condition of the moon, which is like such a globe cooled until its surface is all craters and scoria.

Admitting that the earth has cooled from fusion, we are warranted in concluding that, whenever the vapors began to settle over the solidified but still hot crust, there to make oceans, the rocks exposed to the heated and acid waters would have been everywhere eroded by the chemical action of these waters, and by this means they would have been covered after a while with new rocks. And over those regions where there were emerged or submerged rocks within reach of the waves, the work of the waves in making gravel, sand, and mud would have been added to that of the chemical action.

By such means the *original rock* of the cooled crust would have become nearly or entirely concealed by new deposits;

and it is questioned whether any part of it is now exposed to view. The rocks made out of that crust — not those of the original crust itself — are therefore the Archæan rocks of geology.

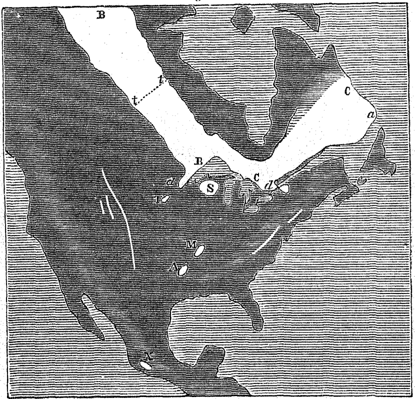
1. Distribution.

The Archæan rocks of North America cover a large surface over the northern portion of the continent, and also some narrow areas elsewhere along the courses of existing mountains. In the accompanying map (Fig. 86) the white areas are the regions of exposed Archæan rocks. The largest extends from Lake Superior northwest to the Arctic seas and northeast to Labrador. It has the shape of the letter **V**, and Hudson's Bay is included within the arms of the **V**. A peninsula from it extends down into Northern New York, including there the region of the Adirondacks. Other Archæan ranges are the Highlands of New Jersey, portions of the Blue Ridge of Pennsylvania, Virginia, and the region farther southwest (and including the Black Hills of North Carolina); small areas in New England, and one or more on the Atlantic border south of New York; a large area south of Lake Superior; and the crest range of the Rocky Mountain region, including the Wind-River Mountains and the eastern range in Colorado.

The arms of the great **V**, or original nucleus of the continent, are parallel respectively to the Atlantic and Pacific coast

lines; the other narrower areas follow the courses of the great mountain chains, and are parallel to the same lines. Geology thus affords a demonstration that even in Archæan time the great outlines of the continent were defined, and that all future progress was carried forward by working on the plan

Fig. 86.



Archæan Map of North America.

thus early laid down. The rest of the continent was under water (and perhaps also some of the ridges just referred to), but it probably lay at no great depth.

Archæan areas exist also in Scandinavia, Bohemia, Scotland,

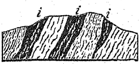
and some other regions. The facts prove that in Archæan time the ocean and continents were, in the main, already outlined. "The waters" of the world had been "gathered into one place," and "the dry land" had "appeared."

2. Rocks.

The Archæan rocks comprise gneiss and granite, syenyte, syenytic gneiss, and other hornblende rocks, with chloritic rocks, quartzyte, limestone, and other kinds.

They include *immense beds of iron ore*, some of them 100 to 200 feet in thickness, vastly exceeding any in later times; for the Archæan was the iron age in the earth's history. These beds of ore occur in Northern New York, Southern New York and Northern New Jersey, Canada, the Marquette region south of Lake Superior, in Missouri, where there are what are called iron mountains, and in many other places. The beds of ore (*i*, Fig. 87) alternate with beds of quartzyte and crystalline schists or slates, and lie between beds of gneiss and hornblendic gneiss, or other rocks of the era, as illustrated in the annexed cut representing a section in Essex County, New York. Hornblende contains much iron, and this is the reason why it is so common a constituent of Archæan rocks.

Fig. 87.



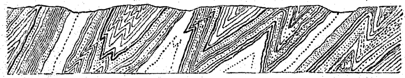
Beds of iron ore (*i*), Essex County, New York.

The rocks were originally sedimentary deposits; for the gneiss, quartzyte, and schists are, as explained on page 71,

altered or metamorphic sedimentary rocks. They were originally deposits of gravel, sand, and mud made by the ocean. The stratification in the gneiss and other rocks is the original stratification of the fragmental beds.

Like other sedimentary deposits the rocks were laid down in horizontal beds. But they are now upturned at all angles, and often folded, showing thereby that, subsequent to their deposition, they underwent the great disturbances that attend mountain-making. Fig. 88 shows the general condition of the rocks

Fig. 88.



General view of folds in the Archæan rocks of Canada.

in the Archæan regions of Canada. The Archæan mountains, including the Adirondacks, the New Jersey Highlands, the mountains of Scandinavia, and others, were then made, if not in part earlier. The original height of these mountains may have been many thousands of feet greater than it is now, for all the earth's agencies of destruction have been engaged in the work of levelling them, ever since that first of the geological ages.

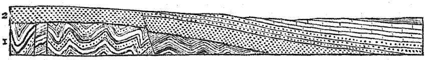
Many Archæan rocks much resemble the crystalline rocks of later time, and as both are without fossils, they may be easily confounded.

The occurrence of beds of iron ore scores of feet thick is one means of distinguishing areas of Archæan age. The ore

often contains some titanium, and this is not common in iron ores of later date. Coarse syenitic rocks and labradorite rocks are characteristic of many Archæan regions, if not exclusively Archæan.

Sure evidence of Archæan age is obtained when fossiliferous beds of the *lowest* Silurian are observed overlying unconformably upturned crystalline rocks, as in Fig. 89. Here the nearly

Fig. 89.



Section from south side of the St. Lawrence, Canada, between Cascade Point and St. Louis Rapids.

1, Gneiss; 2, Potsdam sandstone.

horizontal Silurian beds referred to, No. 2 and those above, were laid down after the beds below were made, and also after their upturning; and consequently the evidence that the latter belong to anterior time is unquestionable.

3. Life.

The earlier part of Archæan time was necessarily without life; for until the rocks and seas had cooled down to the temperature of boiling water, life was hardly possible. Plants of the lowest orders can bear a higher temperature than the lowest of animals, and were probably the first living species.

Although the evidence is not conclusive that either plants or animals were living in the Archæan seas, — since if fossils once were present in the rocks, they have been obliterated by

the crystallization of the beds, — the existence then of the simplest kinds is thought to be highly probable. Some of the beds contain great quantities of *graphite*, the material of which lead-pencils are made. Now (1) graphite is nothing but carbon (page 9), the essential principle of mineral coal, and (2) mineral coal was formed from plants; moreover (3) mineral coal has been found in crystalline rocks converted into graphite. Here, then, is evidence favoring the probable existence of plants; and if of any, of Sea-weeds, since the Lower Silurian has afforded relics of no plants but Sea-weeds. Along with true Sea-weeds there were probably *Diatoms*, as these minute species are the simplest of water-plants.

The occurrence of *limestone* strata is also thought to favor the idea of the presence of plants or animals, since the limestones of the world are almost all of organic origin. Masses somewhat coral-like in texture have been described as fossils, under the name of *Eozoon* (from the Greek for *dawn-life*), and referred to the group of Rhizopods, described on page 32. But there is doubt as to their being true fossils, some regarding them as of mineral origin. Rhizopods are the simplest of all animal life, and the kind most likely to have been associated with Diatoms over the sea-bottom.

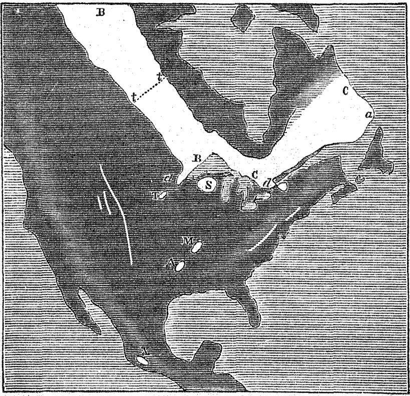
Whenever the earliest plant, however minute, was created, a new principle — that of life — was introduced, which should subordinate physical forces to its uses. Progress in a system of life became thereafter the subject of chief interest in the world's history.

II. — Paleozoic Time.

1. Silurian Age, or Age of Invertebrates.

THE term Silurian comes from a region in Wales where the rocks occur, and which was formerly occupied by a tribe of ancient Britons called the Silures. The age is divided into the era of the *Lower* Silurian and that of the *Upper* Silurian.

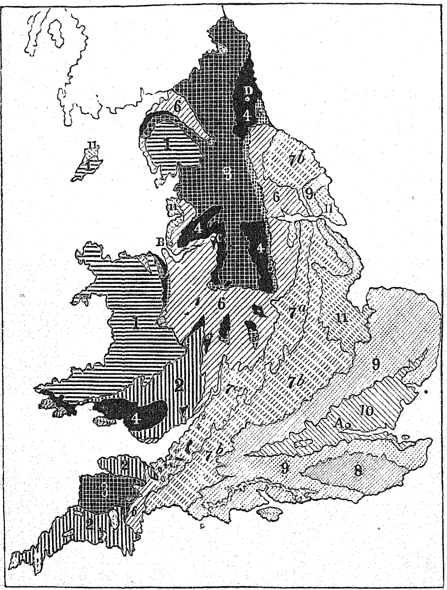
Fig. 90.



Archæan Map of North America.

The map of the Archæan dry land, here repeated, shows to the eye the part of the North American continent over which

Fig. 91.



Geological Map of England.

The areas lined horizontally and numbered 1 are Silurian Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oölyte (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London, B, Liverpool, C, Manchester, D, Newcastle.

the following Silurian beds might have been spread out: for

the beds are all *marine,* and must have been made in the part covered with water, — the shaded part in the map. The circumstances were in the main similar on the other continents. In Europe (Great Britain included) the Archæan dry land lay mostly to the northwest, and the larger part of the rest of the continent was receiving marine deposits.

The areas in North America, east of the Rocky Mountain region, and over which Silurian rocks are exposed to view, are those which are lined horizontally in the map on page 105. The Silurian regions in England are distinguished in the same way on the accompanying map (Fig 91); they are confined to Western England and Wales.

1. Lower Silurian.

1. Rocks.

The rocks of the Lower Silurian era are mainly sandstones, shales, conglomerates, and limestones.

The same is true for all succeeding eras in geological history; for sand-beds (the source of sandstones), mud-beds (the source of shales and argillaceous sandstones), and limestones have been always in progress from this time onward in some part of each continental region. Moreover, sand-beds have never been forming in any region without the making of mud-beds in the waters not far distant, just as now happens along sea-shore regions; for the grinding which produces the former produces also the latter. Nevertheless, the continental areas

over which sand-beds, mud-beds, and limestones were accumulating have varied greatly through the successive periods, owing to variations in level and other causes; and at times the larger part of the continental sea has been given up to limestone-making.

The following is the succession of Lower Silurian rocks in North America.

1. In the early part of the era, called the *Primordial* (meaning *the first in order*), sand-beds — now called the Potsdam sandstone, from a locality in Northern New York — were spread out over wide areas in North America, and especially about the shores of the Archæan dry land; but shales and limestones were forming in some places more or less remote from these shores.

These earliest Silurian sandstones and shales have the layers sometimes marked with ripples, or with mud-cracks, or with the tracks of the animals of the era; and they thus show that they were not made in deep water, but, instead, that they were either the sea-beaches or the off-shore sand-flats or mud-deposits of the era; and that part of the time they were above the water's level, exposed to the drying air or sun, for only thus can mud-cracks be made.

2. As the era advanced, limestone strata (magnesian limestones, mainly) of great extent were formed over the region of the Mississippi Valley, or the Interior region of the continent, while sandstones and shales with but little limestone were ac-

cumulating in the area — then a shallow sea — now occupied by the Appalachian Mountains.

3. Next a limestone — the Trenton limestone — was in progress over both the Appalachian region from the Green Mountains to Alabama and the Interior region, and also far west and north, — the most extensive limestone formation in the world's history. The limestone was named from Trenton Falls, on West Canada Creek, near Utica, New York, where the gorge is cut through it. It includes the Galena or lead-bearing limestone of Illinois and Wisconsin.

4. Finally, limestone-making was again confined almost wholly to the Interior region, and the Appalachian area, including New York and the Green Mountains on the north, was receiving fragmental deposits for sandstones, shales, and conglomerates.

In Great Britain there are, first, slates and sandstones of great thickness in the Longmynd and Wales, overlaid by the "Lingula flags" (the equivalent of the Potsdam sandstone); above these, other slates and flags (laminated sandstones), with some layers of limestone, including the Llandeilo flags, the Bala beds, and the Lower Llandovery in South Wales, — all making one conformable series.

2. Life.

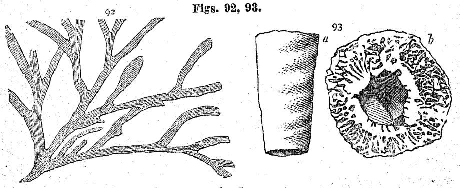
The seas abounded in life, but no trace of anything *terrestrial* has yet been found.

The plants found are all sea-weeds. One of the specimens

is represented in Fig. 92. Some thin deposits of coal occur in one of the formations, which are supposed to have come from buried sea-weeds, or else from animal material.

The animals are all *Invertebrates;* in other words, no trace of a Vertebrate, not even of the lowest of Fishes, has yet been discovered among the animal relics. But all the four sub-kingdoms of Invertebrates are represented, — the Protozoan, the Radiate, the Molluscan, and the Articulate.

Figs. 92, 93.



Sea-weed. — Sponge.

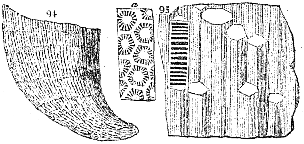
Fig. 92, Buthotrephis gracilis; 93, Archæocyathus Atlanticus.

Protozoans. — Among Protozoans there were Rhizopods and Sponges. One of the Sponges is represented half the natural size in Fig. 93 *a,* and a transverse section of it, natural size, in Fig. 93 *b.* The irregular cellular structure, with the absence of radiating plates, is evidence that it is not a coral.

Radiates. — The Radiates include Corals, Crinoids, and Star-fishes. Fig. 94 is a side-view of one of the conical corals of the Trenton limestone; the top is a cup, radiated with plates, somewhat like Fig. 15, page 29. When living, the flower-like

animal had no doubt its beautiful colors, like those of modern time, and its aspect may be quite well represented by Fig. 16, page 30.

Figs. 94, 95.



Polyp-Corals.

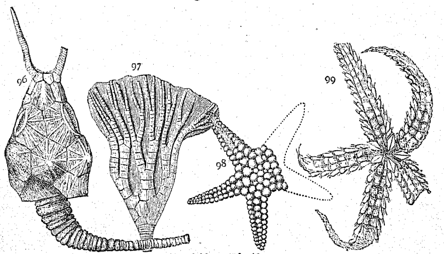
Fig. 94, Petraia corniculum; 95, Columnaria alveolata; 95 *a*, top view of same.

Another coral, honeycomb-like in its columnar structure, is represented in Fig. 95. The cells are radiated, as shown in Fig. 95; but in a vertical section (as seen in such a section of one of the cells in Fig. 95 *a*) the cells are crossed by horizontal partitions. The coral has been found in masses several feet in diameter.

Figs. 96 – 99 represent some of the Crinoids and Star-fishes. Fig. 97 shows one of the Crinoids of the Trenton limestone, though not quite a perfect one, as the arms are broken off at the tips, and the stem below (by which it was attached to the rock of the sea-bottom, and which may have been three or four inches long) is mostly wanting. The name Crinoid means *lily-like;* but the petals or rays of the flower-like animal consist of small pieces of limestone (the secretion of the animal) fitting well together. Fig. 96 shows the form of another kind of Crinoid, — one of very irregular shape; its stem when living

was run down into the mud of the sea-bottom, instead of being attached to a rock. Figs. 98, 99 are two of the Star-fishes of the ancient seas, related to the modern Ophiurans.

Figs. 96-99.



Asterioids. — Crinoids.

Fig. 96, Pleurocystis filitextus; 97, Lecanocrinus elegans — **Crinoids**: Fig. 98, Palæaster matutina; 99, Tæniaster spinosa.

Mollusks. — The Mollusks were of various kinds, all the principal grand divisions of the class having been represented by species. Far the most abundant were what are called *Brachiopods*, a group that has comparatively few kinds in modern seas. One of the earliest Brachiopods from the Potsdam sandstone had a shell not larger than a finger-nail; a large specimen of it is represented in Fig. 100. It is called a *Lingula* (or *Lingulella*), from the Latin *lingua*, a *tongue*, in allusion to the tongue-like shape of some species. A related species is found in the *Lingula flags* of Great Britain. When living

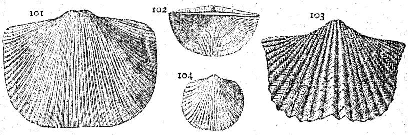
Fig. 100.

Lingulella prima.

it was fixed to the sea-bottom by a fleshy stem proceeding downward from the pointed end or beak of the shell, and passing into the mud or sand; and as the shells are often in great numbers together, they must have grown thickly over the sandy or muddy surface.

Other common Brachiopods from the Trenton limestone are represented in Figs. 101 to 104.

Figs. 101-104.

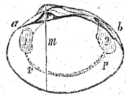


Brachiopods.

Fig. 101, Leptæna sericea; 102, Orthis occidentalis; 103, O. lynx; 104, O. testudinaria.

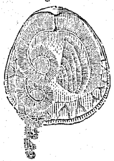
The shells have two valves like those of a clam or oyster; but they are unlike common Bivalves in their symmetrical form; a line let fall from the beak divides them into equal halves, whereas in a Clam, as shown in Fig. 105, such a line divides the shell very unequally. Moreover, the mouth in a Brachiopod is at the middle of the shell, whereas in common Bivalves it is toward one end (near *a*, in Fig. 105); and further, one valve is the *upper* and the other the *lower*, while in a Clam, and related kinds, one is the *right* and the other the *left*. Thus the

Fig. 105.



animal in this ancient group called Brachiopods has a position in its shell just transverse to that of a Clam. The animal is also peculiar in having two spiral fringed arms, and to this the name, from the Greek for *arm-foot,* alludes. Fig. 106 shows these arms in a modern species; one of the pair is rolled up spirally in its ordinary position, while the other is thrown out. The animal has no gills or branchiæ. The Trenton limestone was made largely of the shells of Brachiopods, Crinoids and Corals having contributed little toward it.

Fig. 106.



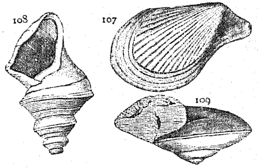
Rhynchonella psittacea.

The Clam and Oyster and other ordinary Bivalves have a thin fold of the skin lying like a mantle over the body against the shell; then, inside of the mantle and either side of the body, thin leaf-like gills or branchiæ; and then the body with no arm-like appendages. In allusion to the thin lamellar branchiæ, they are called *Lamellibranchs.* There were some Lamellibranchs in the Lower Silurian, but they were few compared with the Brachiopods. Fig. 107 represents one of them, related to the Mussel of modern sea-shores.

There were also some spiral shells, two of them of the forms shown in Figs. 108, 109. They belong to the tribe of *Gasteropods,* so called because the animal crawls on its ventral surface. The ordinary spiral marine shells, and also the common snail, are of this tribe. The snail may be often

seen crawling thus with its shell over its back; and the marine species when living, if put into a jar of salt water, will soon be found in motion over the glass.

Figs. 107-109.

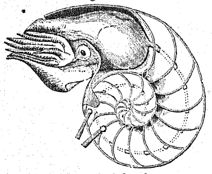


Mollusks.

Fig. 107, Avicula Trentonensis; 108, Murchisonia bicincta; 109, Pleurotomaria lenticularis.

There were also many species of the highest division of Mollusks, — those related to the Nautilus, and called *Cephalopods*, because the animal has the head furnished with stout arms for clinging; from the Greek for *head* and *feet*. A modern Nautilus, with the animal in its shell, is represented in Fig. 110. The shell has transverse partitions, or is *chambered*, and in this differs from the shell of the Snail and all Gasteropods. The animal occupies the large outer chamber, and is peculiar in having large eyes like a fish, and a series of stout arms around the mouth provided with suckers for clinging. A different kind of Cephalopod, from modern seas, is represented in Fig. 111, — a kind having no external shell, but instead a thin internal bone (Fig. 111 *p*), but with

Fig. 110.

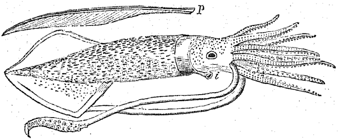


Modern Cephalopod.

Nautilus (× ⅓).

large eyes and a series of arms around the mouth, as in the Nautilus. In the Lower Silurian era there were species of Nautilus, but quite different ones from those of later

Fig. 111.

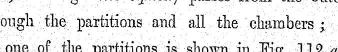


Modern Cephalopod.

The Calamary or Squid, Loligo vulgaris (length of body, 6 to 12 inches); *i*, the duct by which the ink is thrown out; *p*, the "pen."

time. But the earliest Silurian species of Cephalopods and the largest had straight shells, like that of a Nautilus straightened out,—whence the name *Orthoceras*, meaning *a straight horn*. One of them, from the Trenton limestone, is represented in Fig. 112; it has partitions like the shell of the Nautilus.

Fig. 112.



Cephalopod.

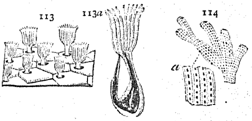
Orthoceras junceum.

In both the Nautilus and the Orthoceras a tube (called the *siphuncle*, meaning *little siphon*) passes from the outer chamber through the partitions and all the chambers; and the hole in one of the partitions is shown in Fig. 112 *a*. Some

of the shells of species of Orthoceras from the Trenton limestone are as large round as a flour-barrel, and must have been from twelve to fifteen feet long.

Another kind of Mollusk, of quite minute size, makes corals. The animals look like polyps *externally*, as shown in Fig. 113, which represents them enlarged, projecting out of their cells. Fig. 114 is a view of one of the delicate Lower Silurian corals, and the dots show the positions of the little cells of the animal. The species are called *Bryozoans*, meaning *moss-animals*, the name alluding to the corals, which are sometimes moss-like in delicacy and form. Although so small, these corals are a prominent constituent of some of the Silurian limestones.

Figs. 113, 114.



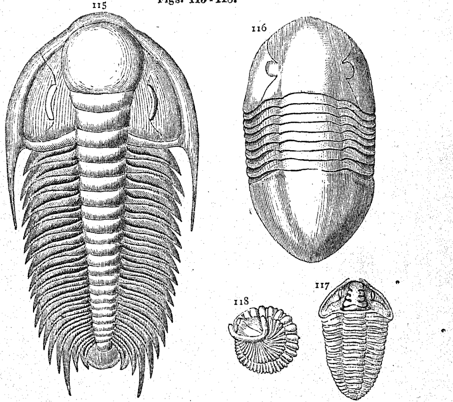
Bryozoans.

Fig. 113, Eschara, showing animals extended out of their cells (× 8); 113 *a*, one of the animals removed from its cell more enlarged; 114, Ptilodictya fenestrata, a Lower Silurian species, natural size; 114 *a*, portion of surface of same enlarged.

Articulates. — The Lower Silurian Articulates that have been made out are either Worms or Crustaceans; no Insects or Spiders having been present, since these are *terrestrial* species. The most remarkable of the Crustaceans, and the highest species of the world at the commencement of Lower Silurian time, and later in this era second only to the Orthocerata, were the *Trilobites*, — so named because the body has *three lobes* or divisions longitudinally, as shown in Figs. 115 to 117. One

of the very earliest species is represented in Fig. 115; it was a gigantic species, the figure being only one third the natural length. It has some resemblance to a lobster, and yet is very different. The position of the large eyes is apparent on the

Figs. 115 - 118.



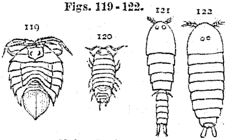
Trilobites.

Fig. 115, Paradoxides Harlani (× ⅓); 116, Asaphus gigas (× ⅓); 117, Calymene Blumenbachii; 118, same rolled up, as it is often found.

head shield. Two other species, from the Trenton, are represented in Figs. 116, 117. The latter is shown folded up in Fig. 118, a common condition of the specimens. The forms of three modern species of Crustaceans having some resem-

blance to the ancient Trilobites are shown in Figs. 119 to 122. Figs. 121, 122 are female and male of the same species. But the Trilobites differed from all these in having had no true legs. They are supposed to have had only thin fleshy plates, for swimming.

Figs. 119-122.



Modern Crustaceans.

Fig. 119, a species of Serolis (× ½); 120, species of Porcellio; 121, 122, female and male of Sapphirina iris.

The earliest life of the Lower Silurian was made up largely of Crinoids, Brachiopods, Worms, and Trilobites. It was almost all stationary life; that is, the most of the species were attached to the sea-bottom by stems. Such were all the Crinoids and Brachiopods. Trilobites swam free; but, having only swimming legs, they probably often attached themselves to the rocks, like the shells called Limpets. Afterward there were Mussel-like shells and corals, which were also attached species, — Mussels living attached to rocks by a byssus or horny threads. Besides these there were the locomotive species, Gasteropods and Orthocerata; the latter may have given much activity to the seas, for Cephalopods are not snail-like in pace, like all Gasteropods, but fleet movers, like fishes. Yet these ancient species, with their long unwieldy shells, must have been slow compared with the Cephalopods of later time.

The life of the Lower Silurian changed much in species during its progress. The era has been divided into three periods:

no animals of the earlier part of the first of these periods — the Primordial — existed in the second, and none of the earlier part of the second existed in the third. Moreover, species were disappearing and others appearing through each of the successive periods.

3. Mountain-making.

The close of the Lower Silurian was a time of upturning and mountain-making in North America, Great Britain, and Europe. The Green Mountains, from Canada to southern Connecticut, and perhaps other heights to the southwest, were then made. The rocks — which include a great limestone formation (the upper part of which is referred to the Trenton) and also various fragmental rocks overlying the limestone — were folded and crystallized by the heat produced by the disturbance added to that from the earth's depths, and were thus changed at the time to metamorphic rocks: the fossiliferous limestone, to white and clouded crystalline or architectural marble, — of which Canaan in Connecticut, Lee in Massachusetts, and Rutland in Vermont afford noted examples; the quartzose sand-beds, to quartzyte; the mud-beds, to gneiss, mica schist, and other crystalline rocks.

In Great Britain the Lower Silurian formations, which are throughout conformable, are upturned so as to lie unconformably beneath the beds of the next era, — the Upper Silurian. The elevation of the Westmoreland Hills, of the mountains in

North Wales, and of the range of Southern Scotland from St. Abb's Head, on the east coast, to the Mull of Galloway, has been referred to this era.

The maximum thickness of the Lower Silurian rocks of Britain has been stated to be over 40,000 feet. In the Green Mountain region it was probably not less than 20,000 feet; in Pennsylvania, about 11,000 feet; in Illinois, about 800; in Missouri, nearly 2,200 feet.

2. Upper Silurian Era.

1. Rocks.

The rocks of the Upper Silurian also are sandstones, conglomerates, shales, and limestones.

1. There was first in progress, during what has been called the *Niagara* period, the formation which includes the Niagara limestone, — which, like the Trenton limestone, was one of the great limestone formations of ancient time. In Western New York and to the southwest along the Appalachian region — still a part of the continental sea — the earlier beds forming were a series of sandstone strata (the Medina sandstone), somewhat pebbly below and argillaceous above; then other argillaceous sandstones, and in them a bed of red iron ore, with a little limestone in the upper part; then the Niagara shale and limestone, the strata at Niagara Falls, where the upper 80 feet are limestone and the lower 80 feet shale. To the west of New York, the Niagara shale formation is of little extent,

while the limestone spreads very widely, reaching into Iowa and Tennessee.

The layers of the Medina sandstone often have ripple-marks, mud-cracks, wave-marks, and other evidences of mud-flat or sand-flat origin, showing that Central and Western New York, with the region to the southwest, was then an area of great sand-flats over an interior sea; but later this interior sea was more open and clearer; so that there was less sediment, and the life required for making limestones flourished.

In Great Britain the Wenlock shale and limestone are of the age of the Niagara shale and limestone. They are in view between Aymestry and Ludlow, near Dudley, and elsewhere. The limestone, like the Niagara, is full of fossils.

2. Afterward the *Salina* formation, noted for its salt, was made. Its clayey rocks and salt show that Central New York, the borders of Canada to the west, and part of Michigan were then the site of a great salt basin, where sea-water evaporated, impregnating the mud of the shallow sea with salt, or making deposits of rock-salt. The brines of Salina and that vicinity in New York are salt-water wells, obtained by boring down to this saliferous rock; and at Goderich in Canada there is a bed of rock-salt 14 to 40 feet thick. Other salt-bearing rocks were made at the same time in Virginia.

3. Next followed another limestone formation of less extent than the Niagara, called the *Lower Helderberg*, from the Helderberg Mountains southwest of Albany, where it occurs. It

extends southwestward along the Appalachians; also through parts of the Mississippi Valley where it rests directly on the Niagara limestone. It also occurs at some points in the Connecticut Valley. A sandstone — the Oriskany sandstone — overlies it in Central New York and along the Appalachian region, and in some places to the west, from Ohio to Missouri.

Following the Wenlock group in Great Britain there is the Ludlow group, consisting of sandstones, shales, and the Aymestry limestone, corresponding in age with the later part of the American Upper Silurian.

2. Life.

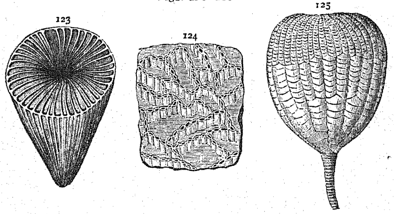
1. Plants. — As in the Lower Silurian, sea-weeds were abundant; but before the close of the era there were also terrestrial plants. The species were not Mosses of the *lower* division of Cryptogams, or flowerless plants, and not Grasses, but species of the Ground-Pine tribe, or Lycopods, — a section of the *highest* Cryptogams. They are described beyond, in the account of the Devonian plants. It cannot be affirmed that there were no Lichens or Fungi over the Silurian rocky lands, or those of earlier time; for such terrestrial species, if existing, would not have become fossilized, since the rocks are mainly of marine or marsh origin. But that there were no Mosses may be safely inferred from the absence of all fossil Mosses from the rocks of the following Devonian and Carboniferous ages.

2. Animals. — The animals included species of all the grand

divisions existing in the Lower Silurian, Protozoans, Radiates, Mollusks, and Articulates, with the same great preponderance of Brachiopods among Mollusks, and Trilobites among Articulates. In addition, before the close of the era, there were Fishes in the seas, the earliest of Vertebrates. No remains of terrestrial animal life have yet been found.

A few figures of the Invertebrates are here given. Figs. 123, 124 represent two of the corals of the Niagara period;

Figs. 123-125.



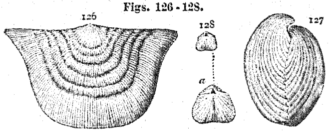
Polyp-Corals. — Crinoid.

Fig. 123, Zaphrentis bilateralis; 124, Halysites catenulata. — Crinoid: Fig. 125, Stephanocrinus angulatus.

Fig. 123 related to the coral of the Lower Silurian, figured on page 119; Fig. 124, a coral imbedded in limestone, which looks, in a section of the limestone, a little like a chain, or a string of links, and has hence been called Chain-coral. Fig. 125 shows the form of one of the Niagara Crinoids.

Some of the more common Brachiopods of the Niagara group are represented in Figs. 126-128.

Figs. 126-128.

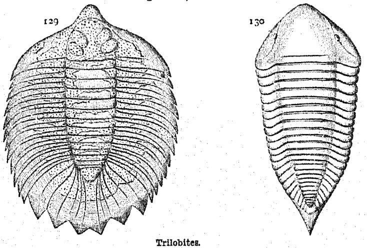


Brachiopods.

Fig. 126, Strophomena rhomboidalis; 127, side-view of Spirifer Niagarensis; 128, Orthis bilobus; 128 *a*, enlarged view of same.

The following are figures of two of the larger Trilobites. Both figures are reduced views, Fig. 129 being but one third the natural length, and Fig. 130 one fourth.

Figs. 129, 130.



Trilobites.

Fig. 129, Lichas Boltoni (× 1/3); 130, Homalonotus delphinocephalus (× 1/4).

The fishes were related to the modern Sharks and Gars. Descriptions of the kinds are given under the Devonian, the specimens of Devonian rocks being more perfect and affording better illustrations of the subject.

3. Observations on the Silurian Age.

1. The distribution of the emerged lands of North America at the close of Archæan time led us to the conclusion (page 108) that the continent was then already defined in area, and its plan of future progress made manifest. The facts respecting the Silurian rocks sustain this view, and show how the work of completing the continent went on through the Silurian era. It has already been explained, by reference to the map of the Archæan dry land, on the same page, that rock-making, and therefore progress, was confined to the submerged part of the continent. The map shows the position of the coast-line along which the waves broke when the Silurian age began, making the sea-beach deposits and sand-flats that now form part of the Potsdam sandstone. The Appalachian region must have been one of the areas of great sand-flats or reefs, for its eastern side was the course of a range of Archæan mountains; and the Rocky Mountain region, for the same reason, was probably another of the shallower portions of the continent. The Lower Silurian continental sea had its greatest depth over the intermediate Interior region, of which the present Gulf of Mexico was then the southern part. These inferences are sustained by the whole course of the history.

2. With the progress of the Silurian the dry land of the north received a gradual extension southward, southeastward, and southwestward. This was the direction of growth. Shore-

lines of the successive periods were more and more remote from the old Archæan sea-shore, for the limits of the successive formations are farther and farther south; so that, at the close of the age, the coast-line in the region of the modern State of New York probably lay a little to the south of the present Mohawk valley, and, extending westward from Niagara over Western Canada, it bent northward around Lake Huron; thence it turned southward so as to cross Northern Illinois before taking its course to the far north parallel with the west side of the Archæan nucleus. These conclusions are deduced from the limits of the Silurian formations, shown on the map on page 105.

3. At the close of the Lower Silurian the Green Mountains were made by an upturning and crystallization of the rocks. A new area of dry land was thus formed between the seas of New York and New England, and the valley of Lake Champlain was a consequence of the uplifting. There was also an upward bending of the earth's crust, but without upturning, over an area from Lake Erie across the Cincinnati region to Tennessee, making another spot of dry land. The Green Mountains were raised parallel to the neighboring Archæan Adirondacks; the Cincinnati uplift was parallel nearly to the Archæan Blue Ridge. Thus progress was strictly after the plan laid down in Archæan time.

Southern and Western New York, and the region of the Alleghany Mountains, remained within the limits of the continental sea through the Silurian age.

4. The rocks of the Interior region of the continent (now the great Mississippi valley) were mainly *limestones* from the beginning of the Silurian to its close; while those of the Appalachian region were mainly *sandstones, conglomerates,* and *shales.* The Trenton limestone spread over both; but, in general, there were fragmental deposits forming over the Appalachian region at the same time that there were limestone deposits in progress to the west of it. The Trenton limestone is an exception; but before the Trenton period closed the Interior region was alone in limestone-making, the Appalachian having become again, as the rocks show, an area of mud-flats and sand-flats.

These facts prove that the Appalachian region was a great reef region through the era, and that over the interior of the continent there was at the same time a clear and wide sea, one seldom swept by sediment-bearing currents. The limestones were made of shells, crinoids, and corals mostly ground up; and their freedom in general from much impurity shows that the marine life had there the pure waters in which it best thrives.

Several of the sandstones and shales contain ripple-marks, mud-cracks, or foot-prints, proving that they were made, not in a deep sea, but in shallow waters, and that the deposits were sometimes exposed above the water's surface.

5. Over 10,000 species of fossils were described from Lower and Upper Silurian rocks up to the year 1872. The species

continued to change through the Upper Silurian era as well as the Lower Silurian; that is, the species of the early part had nearly all disappeared and new species had become substituted before the later part of the era began; and each of the successive subdivisions in the rocks indicates some old feature lost during its progress or in the transition, and some new feature gained.

2. Devonian Age, or Age of Fishes.

The term Devonian was first applied to the rocks of the age in Great Britain by Sedgwick and Murchison, and alludes to the region of South Devon, where the rocks occur and abound in fossils.

Through the age the land had its plants and insects, and the seas their numerous fishes, besides species of all the lower orders of life. The regions of Devonian rocks are those vertically lined on the North American map, page 105, and the map of England, page 114.

1. Rocks.

The Lower Devonian rocks of North America overlie conformably the Upper Silurian, making a continuous series with them.

The age commenced with the era of the Corniferous limestone. This was the great limestone of the Devonian, just as the Niagara was of the Upper Silurian, and the Trenton lime-

stone of the Lower Silurian. It spreads through New York from the Helderberg Mountains south of Albany, where it has been called the *Upper Helderberg* limestone; and stretches westward to the Mississippi, and beyond it into Iowa and Missouri. In New York and along the Appalachian region, it is underlaid by a sandstone or grit rock.

The limestone is in some places a *coral-reef* rock, as plainly so as any coral-reef limestone in modern tropical seas. Near Louisville, Kentucky, at the Falls of the Ohio, it consists of an aggregation of corals, many of large size, and some are standing in the position of growth. The limestone rock often contains a kind of flint called hornstone; and, as the Latin for *horn* is *cornu,* the limestone was named the Corniferous limestone.

The Devonian deposits following this limestone — called often the Upper Devonian — are mostly sandstones and shales, named the Hamilton, Portage, and Chemung beds, from localities in New York; and above these, at the top, there is an extensive conglomerate and sandstone called the Catskill group. These fragmental formations are confined mainly to Southern New York and to the Appalachian region to the southwest.

In parts of the Interior region there were limestones forming when the Hamilton sandstones and shales were in progress; but subsequent to these limestones the Devonian rock formed in the Interior region is mainly a shale of little thickness.

The flagging-stone so much used in New York and the adjoining States is an argillaceous sandstone from the Hamilton beds at Kingston and other places on the Hudson River.

In Great Britain the Devonian formation includes a great thickness of red sandstone in Scotland, Wales, and England, which was formerly distinguished as the "Old Red Sandstone." In South Devon there are limestone and shales in place of red sandstone, and hence a greater abundance of fossils. In the Eifel, Germany, the Eifel limestone is a Devonian coral-reef rock of the age of the Corniferous. Devonian sandstones cover a large area in Russia.

2. Life.

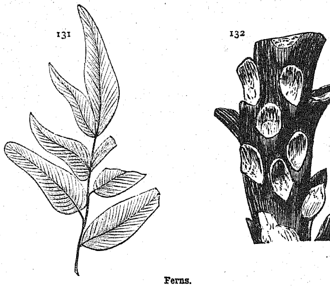
1. Plants. — The plants included, besides sea-weeds, various terrestrial kinds; and among them, in the middle and later Devonian, large forest-trees.

These early species, as stated on page 131, were mostly of the higher Cryptogams.

1. Ferns, some of them Tree-ferns. A portion of one of the Ferns is shown in Fig. 131, and part of the stem of a Tree-fern in Fig. 132.

2. Equiseta. — The modern Equiseta, or Horse-tails (the latter term a translation of the former) have striated jointed stems, which may be pulled or broken apart easily at the articulations. The ancient species had a similar character. A portion of one of these rush-like Devonian plants is

Figs. 131, 132.



Ferns.

Fig. 131, Neuropteris polymorpha; 132, Tree-fern, Caulopteris antiqua.

represented in Fig. 133. One of the articulations of the stem is shown at *a b.* In allusion to its reed-like character it is called a *Calamites,* from the Latin *calamus, a reed.* The plant represented in Fig. 134 is supposed by some to belong to the Equisetum tribe; the word *Asterophyllites* means *star-leaf.*

Figs. 133, 134.

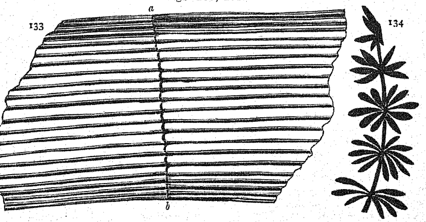
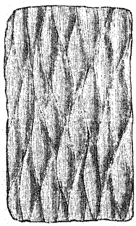
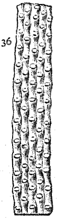


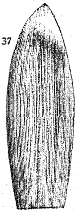
Fig. 133, Calamites transitionis; 134, Asterophyllites latifolia.

3. Lycopods.—The earliest land plants, and those most characteristic of the world in ancient time, were the Lycopods. The little trailing Ground-Pines of our modern woods, so much used for decorating churches at Christmas-time, are examples of Ground-Pines; the close resemblance to miniature Pine-trees is the origin of this name. The earliest of the ancient Lycopods were of small size, but some of those of the Middle Devonian were large forest-trees. Fig. 135 represents

Figs. 135 - 137.

135 

136 

137 

Lycopods. — Gymnosperms.

Fig. 135, Lepidodendron primævum ; 136, Sigillaria Hallii. — **Gymnosperm** : 137, Cordaites Robbii.

a part of the exterior of one of the Devonian Lycopods. The plants are called *Lepidodendrids* (from the Greek for *scale* and *tree*), in allusion to a resemblance between the scarred surface and the scaly exterior of a reptile. The scars are the bases of the fallen leaves, and resemble the same on a dried branch from a spruce-tree. In the true Lepidodendrids the scars are in alternate order, as illustrated in Fig. 135. In

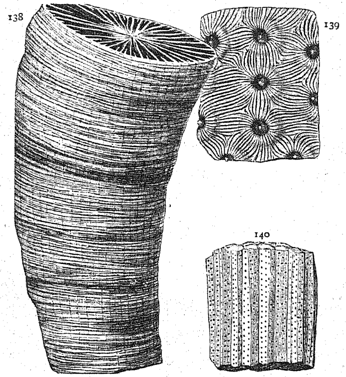
another group, called *Sigillarids*, the scars are in vertical series, as in Fig. 136.

4. Phenogams, or *Flowering Plants.* — Among the Flowering plants there were trees allied to the Yew, Spruce, and Pine, kinds having the simplest of flowers, and the seed naked instead of in pods. In allusion to the latter character they are called *Gymnosperms*, meaning *having naked seeds.* The flowers and fruit are usually in cone-like groups, and in allusion to the cones a large part of the species are *Conifers.* Fig. 137 is probably a leaf of one of the Conifers.

2. Animals. — Protozoans, Radiates, Mollusks, and Articulates were represented by numerous species, as in the Silurian age; and among these Brachiopods were the prevailing Mollusks, Corals the most abundant Radiates, and Trilobites the most common of Articulates. Three of the Corals of the coral-reef limestone (Corniferous limestone) from the Falls of the Ohio, near Louisville, are represented in Figs. 138 – 140. Fig. 138 represents a specimen of one of the large simple Corals, broken at both extremities. The radiating plates are seen at top. The top, when perfect, had a depression rayed with such plates, and to this the name of this ancient group of Corals, *Cyathophylloids*, alludes, it coming from the Greek for *cup* and *leaf.* Some specimens of the species are nearly three inches in diameter at top and a foot long; and, when living, the polyp or flower-animal when expanded was as large as a small-sized sunflower, and probably as brilliant in color.

Fig. 139 shows the surface of a massive coral whose polyps covered the surface like those of Fig. 14, on page 29. The other kind, Fig. 140, is one of the most common; the structure

Figs. 138-140.



Polyp-Corals.

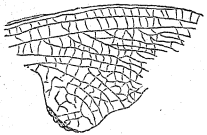
Fig. 138, Zaphrantis gigantea; 139, Phillipsastræa Verneuili; 140, Favosites Goldfussi.

is columnar, suggesting that of a honeycomb, and hence its name, *Favosites,* from the Latin *favus, a honeycomb.*

Besides marine species there were also Insects among terrestrial Articulates. Fig. 141 represents a wing of one of the May-flies of the Devonian world; a gigantic species much exceeding any now known. It measured five inches in spread

of wings. The May-flies or Ephemeræ are species that live in the water during the young or larval state, and when mature fly in clouds over moist places. One of the Devonian kinds could make the shrill sound of a locust.

Fig. 141.



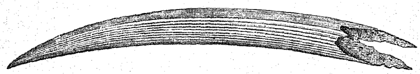
Platephemera antiqua.

In addition to Invertebrates there were Fishes among Vertebrates. The remains of the Fishes are the head, teeth, large spines that formed the front margin of the fins, and also the whole body with its scales; but never the back-bone (vertebral column), as this was cartilaginous and not bony, and hence decayed on burial.

The species included are (1) Sharks; (2) Gars or *Ganoids;* and (3) intermediate kinds called *Placoderms.*

1. Sharks.—The remains of the sharks are either the teeth, the shagreen, or hard, rough-pointed covering of the body,

Fig. 142.



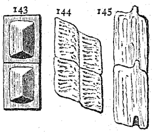
Fin-spine of a Shark.

and the large spines with which the front margin of the fins are sometimes armed. Fig. 142 represents one of the fin-spines of a shark of the Corniferous period, two thirds the full length. The shark was one of great size, as the length

of the spine indicates. Some of the sharks had rather blunt cutting teeth; but the most common kind, related to the living *Cestracion* of Australian seas, had a pavement of bony pieces over the inner surface of the lower jaw, making the mouth a formidable grinding apparatus, fit for cracking Brachiopods and the like.

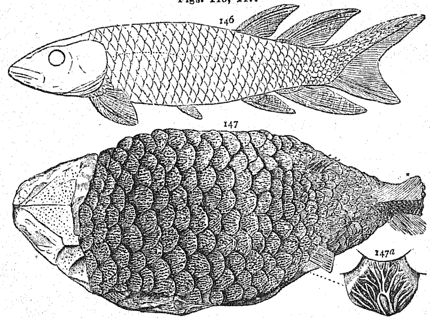
2. Gars or *Ganoids.*—The Gar-pikes of the Mississippi and the Great Lakes, now a rare kind of Fish in the world, are examples of the type of Fishes that was exceedingly abundant in species in the Devonian Age. The scales of Gars are bony and shining, unlike those of ordinary modern Fishes, and to this, Agassiz's name, *Ganoid* (from the Greek for *shining*), refers. In many species the scales are set side by side with a special arrangement for interlocking at one margin after the fashion of the tiles on a roof; while in others they are put on more like shingles, or in the way common in ordinary fishes. Figs. 143, 144 represent two kinds of tile-like scales; and 145, the under surface of two of the latter, showing how they are secured to one another. Figs. 146, 147 represent two specimens of the Ganoid fishes of the Devonian. The tail in Fig. 146 has a peculiarity that belonged to all of the ancient fishes; that is, the vertebral column extends to its extremity. In Mesozoic and Cenozoic species and modern Gars the vertebral

Figs. 143-145.



Scales of Ganoids.

Figs. 146, 147.



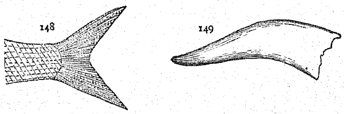
Ganoids.

Fig. 146, Dipterus macrolepidotus (× ½); 147, Holoptychius; 147 *a*, scale of same.

column stops at the commencement of the tail-fin, as in Fig. 148.

Some of the Ganoids of the Middle Devonian whose remains have been found in Indiana and Ohio were of great size.

Figs. 148, 149.



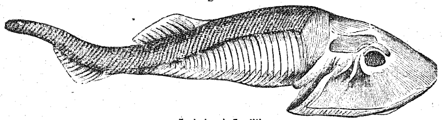
Ganoids.

Fig. 148, tail of Thrissops; 149, tooth of an Onychodus.

One of them had jaws a foot to a foot and a half long, with teeth in the lower jaw (Fig. 149) two inches or more long.

A Devonian fish between a Ganoid and Shark is represented in Fig. 150.

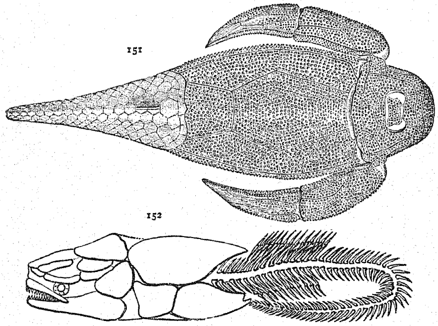
Fig. 150.



Cephalaspis Lyellii.

3. Placoderms. — Still stranger forms are those called *Placoderms.* The body of Fig. 151 is encased in bony pieces

Figs. 151, 152.



Placoderms.

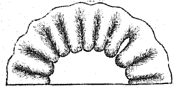
Fig. 151, Pterichthys Milleri (× ⅔); 152, Coccosteus decipiens (× ¼).

like that of a Turtle, and the length of the species, whose remains occur in Russia and Scotland, is supposed to have

been twenty to thirty feet. The term *Placoderm* alludes to the covering of plates, and is from the Greek for *plate* and *skin.*

The teeth of Ganoids are usually very sharp. Sometimes they are small and fine, and grouped so as to make a brush-like surface; but often they are very large and stout. The material of the interior of the teeth, called dentine, is intricately folded, and in allusion to the passages of a labyrinth, such teeth are said to have within a *labyrinthine* texture. A simple form of this labyrinthine texture is represented in Fig. 153.

Fig. 153.



Section of tooth of Lepidosteus osseus.

The facts reviewed with reference to the life of the Devonian teach that during the progress of the age the marshes and dry land were covered with jungles and forests; that the trees were without conspicuous flowers, and the most of them with no true flowers at all; that the seas were brilliant with living Corals, as well as Crinoids, and abounded in Brachiopods and Trilobites; that they also had their great fishes,— Sharks, Gars, and Placoderms. The land, too, had its swarms of Insects, and probably also its Spiders to spread their webs for the May-flies, although no relics of them have yet been found.

3. Mountain-making.

The Devonian age passed quietly for the larger part of the North American continent, without any tilting of the rocks;

yet not without wide, though small, changes of level, varying the limits and depth of the Interior sea; such changes of level and of limits being indicated by the varying limits of the rocks, all of which are of marine origin. This quiet was not interrupted between the Devonian and Carboniferous eras, as far as yet discovered, except to the northeast in the region of New Brunswick, Nova Scotia, and Northeastern Maine. There an upturning and flexing of the beds occurred, and, as a result, some mountain-making.

The southward extension or growth of the dry land of the continent continued; and, by the close of the Devonian, the shore-line probably crossed the southern portion of what is now the State of New York, — where is the southern limit of the outcropping Devonian, so that all of Canada except the southwest extension north of Lake Erie, nearly all of New York, and much the larger part of New England, were above the sea-level, together with Wisconsin and the borders of the adjoining States. There was probably also an island, trending north-northeast, over the Cincinnati region (page 135), and another about an Archæan area in Missouri. See map, page 105.

3. Carboniferous Age, or Age of Coal-Plants.

The Carboniferous age was the time when the most extensive coal-beds of Europe and America were formed. The name *Carboniferous* is from the Latin *carbon, coal.*

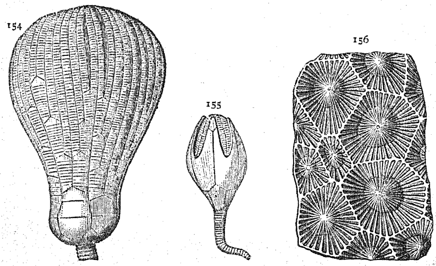
1. Rocks. — Coal-measures.

1. The age commenced with a marine period, — the Subcarboniferous, — in which a large part of the North American continent was under the sea, though not at great depths, and Great Britain and Europe also were to a large extent submerged. During it, limestone strata, with some intervening sand-beds, were in progress in portions of Great Britain and Europe, and over much of the Mississippi basin or the Interior region; and, at the same time, great fragmental deposits, making sandstones, shales, and conglomerates, were laid down along the Appalachian region from the borders of New York southwestward, the thickness of which was five times as great as that of the limestone strata.

The limestone was formed to a great extent of Crinoids, and has been called *Crinoidal limestone.* The Crinoids were of numerous species and very various forms. One of the most perfect specimens is represented in Fig 154, only the stem below being wanting. The figure shows the numberless stony pieces — really blocks of limestone material — of which it consists, and which ordinarily fell to pieces when the animal died, as there was little animal membrane to hold them together. The animal opened out its arms at will, and when expanded, the breadth of the flower-like summit in this species was about three inches. The stem below, when entire, was probably a foot or more long. The little disks of which the stem

in Crinoids consists, looking like button-moulds, are common fossils in the limestones. (See page 34.) Some of them are an inch in diameter. Fig. 155 represents another kind of Crinoid, which was without arms, called a *Pentremites,* from the Greek for *five,* the form of the stem being approximately five-sided.

Figs. 154-156.



Crinoids. — Coral.

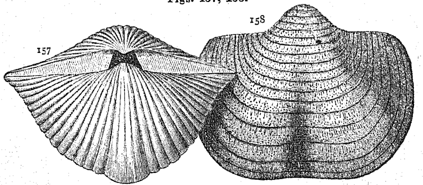
Fig. 154, Zeacrinus elegans; 155, Pentremites pyriformis. — **Coral**: 156, surface of Lithostrotion Canadense.

There were also Corals; and a top view of the most common of these is represented in Fig. 156. Brachiopods also contributed largely to the rock, as to all earlier limestones: figures of two of them are given in Figs. 157, 158.

2. After the Subcarboniferous period — a period of submergence — began the true Coal period, or that of the *Coal-measures,* as the series of coal-beds and rocks containing them is called. The rocks are mostly sandstones, shales, and conglom-

erates; but in the Interior region of North America there are some intervening limestone strata. The rock at the base of the coal-measures is generally a conglomerate called the *millstone-grit*.

Figs. 157, 158.



Brachiopods.

Fig. 157, Spirifer bisulcatus; 158, Productus punctatus.

The *Coal-beds* contain only terrestrial or fresh-water fossils, and nearly all are plants; while the strata that separate them have sometimes marine or brackish water fossils.

The areas of the coal-measures are the black areas on the maps of North America and England, pages 105, 114.

In North America there is *one* area, the *Acadian*, to the northeast in Nova Scotia and New Brunswick; a *second*, of very small extent in Rhode Island; a *third*, the Alleghany, reaching from near the southern boundary of New York over part of Pennsylvania, Ohio, Kentucky, and Tennessee to Alabama; a *fourth*, in Central Michigan; a *fifth*, the *Eastern Interior*, covering parts of Illinois, Indiana, and West Kentucky; a *sixth*, the *Western Interior*, over parts of Iowa, Missouri,

Kansas, Arkansas, and Texas. The last two were originally united in one, the Mississippi valley now separating them. It has been estimated that the area of the workable coal-beds of the United States is at least 120,000 square miles. The coal area of Nova Scotia and New Brunswick is 18,000 square miles.

The principal coal areas of England are those of South Wales; the great Lancashire region east of Liverpool (B, on the map, p. 114) and Manchester (C); the Derbyshire coal region farther east; and on the northeastern coast, the Newcastle coal-field (D). There are also coal-fields in Scotland between the Grampian range on the north and the Lammermuirs on the south; and others, of Ulster, Connaught, Leinster (Kilkenny), and Munster, in Ireland. The areas of England and Scotland are supposed to have been originally one great coal-field. There are valuable coal-fields of smaller extent in Belgium, France, and Spain, and still smaller in Germany and Southern Russia.

The greatest thickness of the coal-measures in Pennsylvania is 4,000 feet; in Illinois, 1,200 feet; in Nova Scotia, about 15,000 feet. In Great Britian it is 7,000 to 12,000 feet in South Wales, and contains a hundred beds of coal; 7,000 feet in Lancashire, with forty beds of coal; 2,000 feet at Newcastle. The aggregate thickness of the coal-beds of a region is not over *one fiftieth* of that of the coal-measures.

The coal-beds vary in thickness from less than an inch to

30 or 40 feet. The "mammoth vein" of the anthracite region in Pennsylvania is 29 feet thick at Wilkesbarre; but there are some layers of shale in the course of it, — a common fact in all coal-beds. Some coal-beds contain too much earthy matter to be of any value.

The mineral coal is of different kinds. That of Central Pennsylvania and of Rhode Island is *anthracite,* while that of the rest of the country is almost wholly *bituminous coal.* Anthracite is a firm lustrous coal, burning with but little flame, while the *bituminous* coal, as that from Pittsburg and the States west, is less firm and usually of less lustre, and burns with much yellow flame. The flame is due mainly to the fact that part of the carbon is combined with hydrogen (or with hydrogen and oxygen) into a compound that, when heat is applied, becomes a combustible gas or mineral oil. Bituminous coal when heated affords more or less of mineral oil (the material from which kerosene is obtained), although it contains none; the oil or gas is *produced by the heat* out of some carbonaceous material present. Some bituminous coals — especially those compact coals, scarcely shining, called *cannel coal* — afford 50 per cent or more of volatile matter; while anthracite yields very little, and this is mostly the vapor of water.

Coals always contain some impurity which is the "ashes" and "clinkers" of a coal-fire. This ashes or earthy material was largely derived from the plants themselves, and for

the best coals wholly so; but in other cases it is part of the detritus that was from time to time washed over the beds of vegetable débris when they were forming. The coal-beds always contain a little sulphur, — enough to give a sulphur smell to the gases from the burning coal; and the most of it comes from the presence of *pyrite,* a compound of iron and sulphur.

The layer of rock under a coal-bed is often a clayey layer, — called the underclay, — and it is frequently full of the under-water stems or roots of plants. The trunks sometimes project from the top of a bed of coal, as shown in Fig. 65, page 84. Many logs or great trunks lie in the strata that intervene between the coal-beds, which were once floating logs; and multitudes of ferns and flattened stems or trunks of these and other plants are often spread out in the shales, and especially in the bed of rock directly over a coal-bed. Moreover, the coal itself, even the hardest anthracite, has sometimes impressions of plants in it, and, more than this, contains throughout its mass vegetable fibres in a coaly state which the microscope can detect.

Coal was made from plants, and each coal-bed was originally a bed of vegetable material like the peat-beds of the present time in mode of accumulation. (See, on this point, page 40.) The plant-bed having accumulated until several times thicker than the coal-bed to be made out of it, was finally covered with beds of clay or sand; and while thus buried it gradually changed to coal.

Plants when dried are one half *carbon,* — the chief material of charcoal, — the rest being mostly the two gases oxygen and hydrogen; after the change, eight tenths to nine tenths or more of the whole are carbon.

3. The coal-measures are followed in Europe by a series of red sandstones and clayey rocks or marlytes, with a magnesian limestone, constituting the *Permian* group, — so called from the district of Perm, in Russia. In North America the Permian rocks include the sandstones and shales at the top of the coal-measures in Kansas.

2. Life.

1. Plants. — The plants were similar in general character to their predecessors in the Devonian age, though mostly different in species and partly in genera. Of the higher Cryptogams — called *Acrogens* (or *upward growers,* as the word from the Greek signifies), because they can grow into trees — there were (1) *Ferns,* (2) *Equiseta,* (3) *Lycopods;* and of the Phenogams, or flowering trees, there were *Conifers,* or plants of the Pine-tribe. The trees and shrubs grew luxuriantly over the almost endless marshes of the continent, and spread also beyond them over the higher lands.

The features of the vegetation and of the ordinary landscape is shown in the following ideal sketch. The tree at the centre is a Tree-fern, and there are smaller Ferns below. The tree near the left side is a Lycopod of the ancient tribe

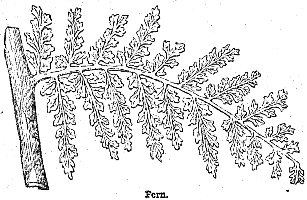
of Lepidodendrids; and in the right corner there are other Lepidodendrids and the trunk of a Sigillaria. In the left corner there are Equiseta. The region is represented as a

Fig. 159.

Carboniferous Vegetation.

great marshy plain with lakes. The lakes of the Carboniferous era probably had their many floating islands of vegetation, carrying large groves like the floating islands of some lakes in India.

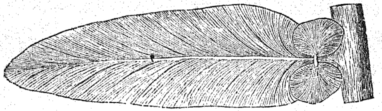
Fig. 160.



Fern.
Sphenopteris Gravenhorstii.

A portion of one of the Ferns is shown in Fig. 160, and of another in Fig. 161. Fig. 162 represents one of the Equi-

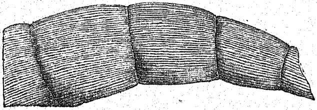
Fig. 161.



Fern.
Neuropteris hirsuta.

seta, a species of *Calamites* (page 140); plants with jointed stems that grew often to a height of 20 feet, and sometimes

Fig. 162.

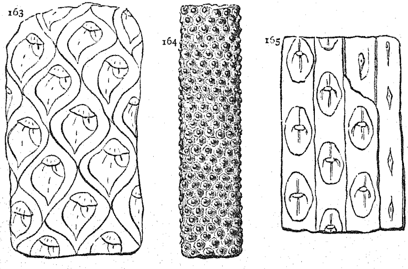


Equisetum.
Calamites cannæformis.

were a foot in diameter, — very unlike the little Horse-tails of modern time.

The Lycopods of the tribe of Lepidodendrids had the aspect of Pines and Spruces, and were 40 to 80 feet or more in height. On some, the slender pine-like leaves were a foot or more long. Figs. 163, 164 show the scars of the outer

Figs. 163-165.



Lycopods.

Fig. 163, Lepidodendron clypeatum; 164, Halonia pulchella; 165, Sigillaria oculata.

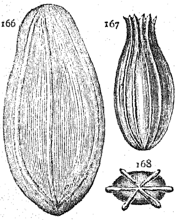
surface of two of the Lepidodendrids arranged, as usual, in alternate order; and Fig. 165 those of a Sigillaria in vertical series. The resemblance of the scars in the latter to an impression of a seal suggested the name *Sigillaria,* from the Latin *Sigilla, seal.*

The cones of the Lepidodendrids and Conifers and the nuts of the latter also occur in the beds. Two of these nuts

are represented in Figs. 166, 167. They are supposed to have belonged to trees related to the modern yew-tree.

Figs. 166-168.

166 167 168



Nuts of Conifers.

Fig. 166, Trigonocarpus tricuspidatus; 167, T. ornatus; 168, view of lower end of same.

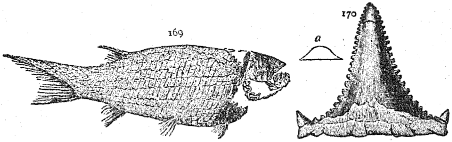
Nearly 500 species of Carboniferous plants have been described from North America, and about the same number from Europe; and of these more than one third were common to Europe and America.

There are also coal-regions in the Arctic islands which have afforded some of the same species of plants that were growing in Europe and America, showing great uniformity in the climate of the era; a fact sustained also by the occurrence in the Arctic deposits of many fossil shells and corals identical with some then living in the seas of Europe and America.

2. Animals. — The seas of the Carboniferous age abounded in Crinoids and Corals among Radiates, and Brachiopods far exceeded in number all other kinds of Mollusks; but in the group of Articulates, while there were many kinds of Worms and Crustaceans, Trilobites were few. Trilobites had been replaced by other Crustaceans, some of which were much like the modern Shrimp. Examples of the Crinoids, Corals, and Brachiopods of the earlier part of the age are figured on pages 151, 152.

Fishes were in great numbers and of large size, and they belonged to the two grand divisions that were especially characteristic of the Devonian, — the *Sharks* (called also *Selachians,* from the Greek for *cartilage,* the Sharks being fishes with a cartilaginous skeleton) and the *Ganoids.* One of the Ganoids of the coal-measures is represented in Fig. 169. It

Figs. 169, 170.



Fishes.

Ganoid: Fig. 169, Eurylepis tuberculatus, from the coal-formation in Ohio. — **Selachian**: Fig. 170, tooth of Carcharopsis Wortheni; *a*, profile of section of same.

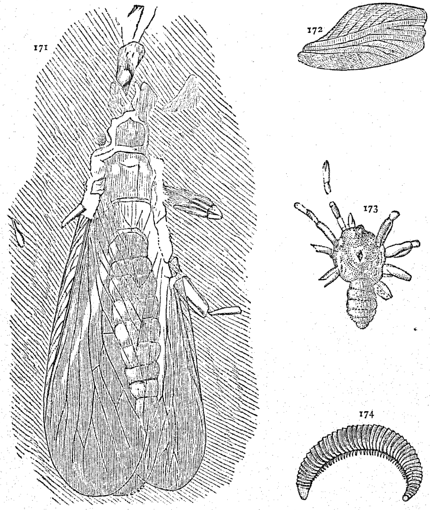
has the vertebrated tail characteristic of all Paleozoic fishes. Fig. 170 shows the form and size of the teeth of one of the sharks of the Illinois region.

The land had its Insects, true Spiders, Scorpions, and Centipedes, and also its land Snails; and among the Insects there were May-flies, Cockroaches, and Crickets. A view of one of the May-flies, twice the natural size, is shown in Fig. 171; of the wing of a Cockroach in Fig. 172; of a Spider, from Morris, Illinois, in Fig. 173; and of a Centipede, from Nova Scotia, in Fig. 174.

Besides these species there were also *Reptiles,* the earliest

relics of which thus far found come from Carboniferous rocks. Footprints of them have been described from the Subcarbon-

Figs. 171-174.



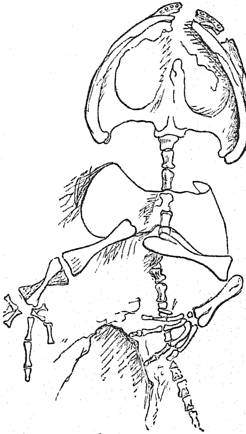
Terrestrial Articulates.

Insects: Fig. 171, Miamia Bronsoni (× 2); 172, Blattina venusta, wing of a Cockroach. —**Spider:** Fig. 173, Arthrolycosa antiqua. — **Centipede:** Fig. 174, Xylobius sigillariæ.

iferous beds of Pennsylvania, indicating a large animal having a tail, — the tail having made its mark on the mud-flat over

which the animal marched. In the Carboniferous beds of Illinois, Ohio, and Nova Scotia skeletons have been found. One of them, from Ohio, is represented in Fig. 175. It has the broad cranium with large open spaces that is found in the Frog and Salamander; but while modern species have a naked skin and no teeth, the Carboniferous kinds were furnished with scales and sharp teeth very much like those of the Ganoid fishes. Frogs and Salamanders belong to the inferior division of Reptiles called *Amphibians.* They are distinguished from true Reptiles (such as Lizards, Crocodiles, Snakes, Turtles) by having gills when young, which serve them for respiration until they become full grown; then the gills drop off, and they use their lungs. The Carboniferous species are believed to have had this low fish-like character in the young state, and thus to have been related to the modern Frog and Salaman-

Fig. 175.

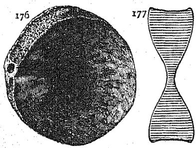


Amphibian.
Raniceps Lyellii.

der, or Amphibians; but, while so, they were greatly superior to the modern representatives of the tribe.

Besides these Amphibians, there were also *true Reptiles.* Fig. 176 represents a vertebra of one of them, from the Nova Scotia coal-measures. The vertebra, as the section in Fig. 177 shows, was concave on both surfaces like those of fishes, and also like those of the *sea-saurians,* found in the rocks of the next geological age, — reptiles that had paddles like whales. Finally, before the last period of the Carboniferous age had passed, there were also still higher Reptiles, — those that lived on the land.

Figs. 176, 177.



Sea-Saurian.

Fig. 176, Vertebra of Eosaurus Acadicus, Marsh; 177, profile of same.

No remains of *Birds* or of *Mammals* have yet been found in any rocks as early as those of the Carboniferous age.

3. Changes during the Progress of the Carboniferous Age.

Changes of level were going on over the North American continent throughout the Carboniferous age; but they were oscillations above and below the sea-level in many alternations, and of the gentlest and slowest kind possible, and not upliftings into mountains. Just such alternations of level had been in progress all through the preceding ages; but the Carboniferous movements were peculiar in this, that the continent

over its broad surface was just balancing itself near the water's surface, — part of the time bathing in it and then out in the free air, and so on, alternately; while, in former times, the oscillations seldom carried the interior region out of the sea, or if it did, only portions at a time. It was peculiar also in the fact that the wide continent lay quiet above the sea-level, with a nearly even surface, *for a very great period of time,* — sufficiently long to make beds of vegetable débris thick enough for coal-beds; many of the coal-beds are *six* feet thick, and some *twenty* or more; and even six feet would require, according to an estimate that has been made, a bed *thirty* feet thick for bituminous coal, and a much thicker one for anthracite.

The Interior of the continent from Eastern Pennsylvania to Central Kansas was a region of vast jungles, lakes with floating grove-islands, and some dry-land forests, and the débris of the luxuriant vegetation produced the accumulating plant-beds. A Cincinnati area of emerged land then divided the continental marsh from Lake Erie to Tennessee; but farther south the eastern and western portions were probably united. The Michigan coal area was an independent marsh region. The Green Mountains separated the Pennsylvania area from those of New England and Nova Scotia; but the two latter were probably connected along the region of the Bay of Fundy and Massachusetts Bay.

The changes of level could hardly have carried up evenly

all parts of the Interior marsh-region from Pennsylvania to beyond the Mississippi; and it is evident that they did not, since it is difficult to make out the parallelism between the beds of the eastern, central, and western portions.

The era of verdure during which a plant-bed was in progress finally came to its end by a return of the salt water over the continental interior which destroyed the terrestrial life; and then began the deposition of sediment covering up the plant-beds and making sandstones or shales or conglomerates, or the forming of limestones. Finally, the continental surface, or wide portions of it, again emerged slowly, putting an end to its marine life, and opening a new era of verdure. Such alternations continued until all the successive coal-beds were made; some of them affecting perhaps the whole breadth of the Interior coal area, others more local. Thus the era was one of constant change; yet change so gradual that only a being whose years were thousands or tens of thousands of our years would have been able to discover that any was in progress.

In Nova Scotia the oscillations went on until nearly 15,000 feet of deposits were formed; and in that space there are 76 coal-seams and dirt-beds; and therefore 76 levels of verdant fields between the others when the waters covered the land. But over that region the waters submerging the region were mainly fresh or brackish waters, since no marine shells exist in the beds, while there are land shells and bones of reptiles. The area was an immense delta in the Carboniferous age at

the mouth of the St. Lawrence, then the only great river of the continent, and the submergences were connected with the floods of the stream as well as changes of level in the crust of the earth beneath.

The Permian period, or the closing part of the Carboniferous age, was an era of gradual submergences, without long eras of verdure or the formation of plant-beds.

4. Mountain-making at the close of Paleozoic Time.

From the beginning of Paleozoic time to its close all changes over the Appalachian region west of the Archæan ridges, southwest of New England, and over the great Interior region of the continent, had gone on quietly, with gentle oscillations of the surface and slight displacements, but no general upturning in any part.

These ages of quiet and regular work in rock-making were very long, for Paleozoic time includes at least *three fourths* of all time after the commencement of the Paleozoic.

Over the *Appalachian* region from New York southward, the Silurian, Devonian, and Carboniferous deposits have great thickness. The amount in Pennsylvania and Virginia has been estimated at 40,000 feet, or *over seven miles.* But over the *Interior* region, where limestones were the most of the time forming, the thickness is from 3,000 to 4,000 feet. These Appalachian deposits, more than ten times thicker than those of the Interior, were accumulating there for the making of a

range of mountains; and at the close of the Paleozoic all was ready and the mountains were made.

These 40,000 feet of deposits were laid down in a great trough made by the gradual sinking of the earth's crust. For the lowest sandstone of the series bears evidence that it was made in shallow waters, as stated on page 116; and the last in the series, the Carboniferous beds, were spread out horizontally just above or just below the surface, the coal-beds proving a small emergence part of the time, and ripple-marks, mud-cracks, and footprints indicating that the sea-level was near by. The coal-measures contain beds of iron ore of great economical importance; and these are evidence that the condition was at times that of a great muddy marsh, probably a salt marsh, the iron ore being a marsh deposit.

If, then, the top and bottom strata were made near the water-level, there must have been seven miles of sinking during the interval between their deposition. Other beds of the series bear like evidence of shallow-water origin; so that the fact is clear that the earth's crust, along what is now the region of the Alleghany Mountains, west of the Blue Ridge, for a breadth of nearly a hundred miles and a length of seven hundred and fifty or more, was slowly sinking, — so slowly that the sediments laid down kept the trough all the time full to the surface, or nearly so.

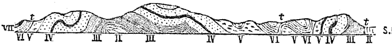
This sinking of the earth's crust over the region, and the concurrent accumulation of sedimentary beds, were the pre-

paratory steps in the mountain-making that was then to go forward, — and steps that took, as above remarked, *three fourths* of all geological time after the Archæan era.

The catastrophe consisted in the (1) folding, (2) fracturing, (3) solidifying, and in part (4) crystallizing of the beds; and also (5) in the change, in Central Pennsylvania, of bituminous coal to anthracite.

The folds were numerous, and involved the whole breadth of the region; and if their tops had not since been worn off by the action of water, some of the folds would now rise over 10,000 feet above the sea-level. Their characters are shown in Fig. 178, of a section from Virginia, extending

Fig. 178.

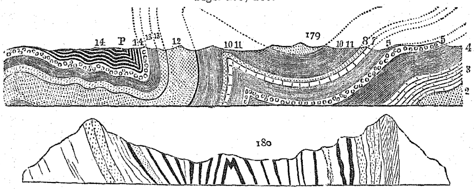


from the southeast on the right to the northwest on the left, over a distance of six miles. It presents an example, as explained on page 84, of the denudation the country has undergone, as well as of the folding.

The coal-formation was involved in the folds, — a fact which proves that the folding began after the coal-beds were formed. Fig. 179 is a section from the vicinity of Pottsville, Pennsylvania, P being the position of Pottsville on the coal-measures. Fig. 180 represents another from near Nesquehoning, Pennsylvania, showing the anthracite beds doubled up, and in part vertical.

1. The folds are steepest and most numerous to the southeastward, or toward the ocean, and diminish to the northwestward. (See Fig. 178.)

Figs. 179, 180.

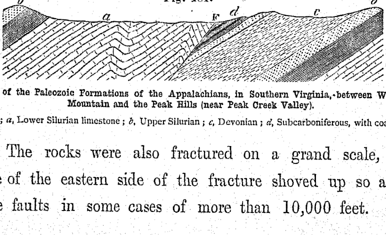


Sections of the Coal-measures.

Fig. 179, on the Schuylkill, Pa.; P, Pottsville on the coal-measures; 14, the coal-measures; 13 to 11, Devonian formations; 8 to 5, Upper Silurian; 4 to 2, Lower Silurian. Fig. 180, Anthracite region, near Nesquehoning, Pa.; the black lines coal-beds.

2. The folds generally have the western slope steepest, as if pressure from the direction of the ocean had pushed them westward; and sometimes the tops have thus been made to overhang the western base. (Fig. 179.)

Fig. 181.



Section of the Paleozoic Formations of the Appalachians, in Southern Virginia, between Walker's Mountain and the Peak Hills (near Peak Creek Valley).

F, fault; *a*, Lower Silurian limestone; *b*, Upper Silurian; *c*, Devonian; *d*, Subcarboniferous, with coal-beds.

3. The rocks were also fractured on a grand scale, and those of the eastern side of the fracture shoved up so as to make faults in some cases of more than 10,000 feet. Fig.

181 represents one of these great faults. The fault is at F; to the right of F is the coal-formation, and to the left, a bent-up Lower Silurian limestone; so that a Lower Silurian rock is brought up to a level with the coal-formation, — a lift, according to Lesley, of 20,000 feet.

4. The rocks were solidified through the aid of the heat caused by the movement of the rocks (page 72); and by the same means the change of the coal to anthracite was caused. This change to anthracite took place where the rocks are most upturned; it diminished westward, and accordingly the coal, on going west, is first a semi-anthracite or a semi-bituminous coal, and then true bituminous coal, as at Pittsburg. The rocks in some regions were crystallized.

5. While there was so much folding and fracturing, there was no chaotic confusion of the rocks produced, the stratification being perfectly retained.

It follows from the facts (1) that the force acted quietly, or with extreme slowness, — for otherwise confusion would have been produced; and (2) that the pressure acted from the direction of the ocean, — the forms of the folds and their greater numbers and steepness in that direction proving this.

Now, *what was the action producing the folding and accompanying effects?*

The earth's crust below the region rested at the time on liquid rock; if it did not, the trough 7 miles in depth could not have been made by the downward bending of the

crust. Suppose the thickness of the crust to have been at the time 100 miles; and that below 100 miles there was fusion and the temperature of fusion. In the making of the trough the crust was bent downward, and as it formed it was kept full of sedimentary beds; so that, at the close of the Carboniferous age, the distance from the surface to the original bottom of the bent crust was increased by 7 miles, making it 107 miles. If, then, the distance down to the temperature of fusion was 100 miles, the bottom of the crust beneath the trough for a thickness of 7 miles must have been wholly or partly melted off. The crust would have been greatly weakened by such a loss, and also by the heat penetrating upward into it; for it had received no corresponding increase of strength from the 7 miles of deposits added, since these were not wholly consolidated. As a consequence, the pressure from the direction of the ocean, resulting from the earth's contraction (page 89), the same that had been making the trough, produced finally a break below and a collapse, and thereby a pressing together of the thick deposits lying in the trough, folding and breaking them; and also raising the upper surface above its previous level, because the width of the base on which they rested was narrowed by the collapse.

These facts respecting the formation of the Alleghany Mountains illustrate the way in which other mountains of folded rocks have been made. The Green Mountains had a similar history: first, a slow subsiding of the crust making a trough,

and a trough that was kept full of sedimentary deposits, and which took the whole of the long Lower Silurian era for its completion (probably half the whole length of Paleozoic time); then a break below, and a collapse producing folds and fractures throughout the region; contemporaneously, the production of heat as a consequence of the friction of the folding and fracturing rocks, which was added to the heat that had come up into the strata from the depths below during the sinking; and the solidification and metamorphism of the various rocks as a consequence of the heat.

Mountains were made in Europe and Great Britain at the same time with the Alleghanies, so that the close of Paleozoic time has its mountain boundary elsewhere besides in America.

Changes in Paleozoic Life at the Close of the Era.

In Paleozoic time Crinoids, Brachiopods, Cyathophylloid Corals, Orthocerata, Trilobites, vertebrate-tailed Ganoid Fishes, and Lepidodendrids, Sigillarids, and Calamites among plants, were characteristic species in each of the classes to which they belong. With the close of it, Trilobites, Lepidodendrids, and Sigillarids became extinct; Cyathophylloid Corals, Orthocerata, and vertebrate-tailed Ganoids nearly so; and, afterward, Brachiopods among Mollusks, and Crinoids among Radiates, were greatly inferior in numbers and importance to other types of more modern character. It is thus that the Paleozoic features of the world passed by.

The characteristics of the following era, the Mesozoic, had in part appeared before the Paleozoic era closed. For Amphibians and true Reptiles were then in existence, — Shrimps and other species among Crustaceans and Insects, Spiders, and Centipedes among Articulates. And the grand division of plants which had its maximum display in the Mesozoic — the *Cycads*, of which an account is given beyond — had some species before the age closed.

The extinction of species at the close of the Paleozoic was so nearly universal that, thus far, no fossils of the Carboniferous age have been found in rocks of later date. But the rocks now in view were those that were made over the continental seas, and, more correctly, over only portions of those seas; and hence they give no facts as to the species of the ocean, and but an imperfect record of those of the continental seas.

III. — Mesozoic Time.

MESOZOIC TIME includes only one age, — the age of Reptiles. The Mesozoic areas on the maps of the United States and England, pages 105 and 178, are lined obliquely from the right above to the left below.

Age of Reptiles.

This age is divided into three periods: —

1. The TRIASSIC: named from the Latin *tria*, *three*, in allusion to the fact that the rocks in Germany have three subdivisions.

2. The JURASSIC: named after the Jura Mountains, on the eastern borders of France.

3. The CRETACEOUS: named from the Latin *creta, chalk*, the formation including the chalk-beds of England and Europe.

1. Rocks.

By the close of the Paleozoic, the Interior region of the American continent east of the Mississippi had become dry land. Accordingly, Triassic and Jurassic rocks were formed only on the Atlantic border east of the Appalachians, and over the western half of the continent beyond Missouri.

These rocks on the Atlantic border cover long narrow areas parallel with the Appalachians from the Gulf of St. Lawrence southwestward. One of them lies along the east side of the Bay of Fundy; another in the Connecticut valley from Northern Massachusetts to New Haven on Long Island Sound; another, commencing in the region of the Palisades, extends through New Jersey and Pennsylvania into Virginia; and others occur in Virginia and North Carolina. These areas are indicated on the map on page 105.

The rocks are mainly red sandstones. In Virginia, near Richmond, and in the Deep River region, North Carolina, there are thick beds of good mineral coal. They contain no marine fossils; the few that occur are either brackish-water or fresh-water. It follows, hence, that the long narrow ranges of sandstone were formed in valleys, parallel with the Appalachians, into which, for some reason, the sea did not gain full entrance.

In Western Kansas, and farther west over the Rocky Mountain region, there are red sandstone strata of great extent, often containing gypsum, but generally without fossils, that are regarded as Triassic. Fossils have been found in rocks of this period in California, and also in British Columbia and Alaska.

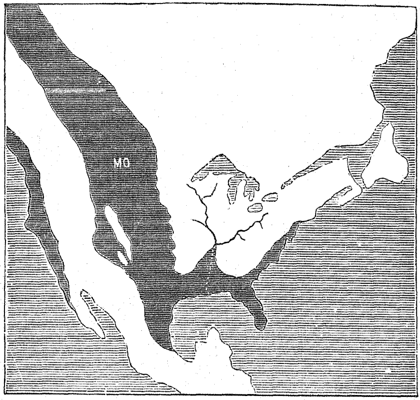
Jurassic beds, with marine fossils, overlie the Triassic of the Rocky Mountain region, west of the summit, making in part the Wahsatch Mountains, the Sierra Nevada, and other ranges.

At the close of the Jurassic period a great geographical change took place in Eastern North America and also west of the Mississippi; for in the Cretaceous period beds *full of marine fossils* were forming all along the Atlantic border south of New York, and over a wide region bordering the Gulf of Mexico; up the Mississippi valley, to the mouth of the Ohio; from Texas northward over Kansas and a large part of the eastern slope and summit region of the Rocky Mountains, perhaps reaching to the Arctic; and also along the Pacific border west of the Sierra Nevada. The outline of the continent when these beds were in progress is shown in the accompanying map (Fig. 182), the shaded portion being the part that was then under water, filled with Cretaceous life and receiving Cretaceous deposits of sediment.

The Cretaceous beds are mostly soft green and gray sandstones, partly compact shell-beds and "rotten" limestone, with hard limestone in Texas, and chalk in Western Kansas. Marine fossils are abundant, and they generally indicate shallow

waters. Over the Rocky Mountain region the beds are in some places 10,000 feet above the sea; showing that the mountains have been elevated to this extent since the beds were made.

Fig. 182.

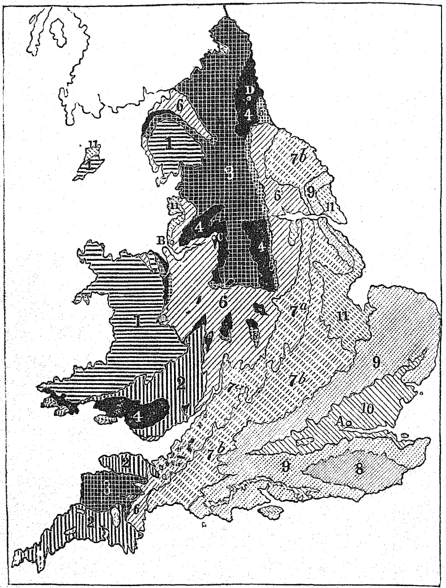


North America in the Cretaceous Period.

MO, Upper Missouri region.

In Great Britain the Triassic beds (No. 6 on the accompanying map, Fig. 183) were red argillaceous sandstones and clay rocks (marlytes) formed in a partly confined sea-basin. At Cheshire they contain a bed of rock-salt derived from the evaporation of the waters of the sea-basin. The Jurassic rocks consist, below, of a limestone called the *Lias* (No. 7 *a*); other

Fig. 183.



Geological Map of England.

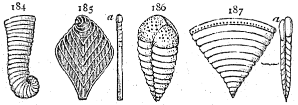
The areas lined horizontally and numbered 1 are Silurian. Those lined vertically (2), Devonian. Those cross-lined (3), Subcarboniferous. Carboniferous (4), black. Permian (5). Those lined obliquely from right to left, Triassic (6), Lias (7 *a*), Oölyte (7 *b*), Wealden (8), Cretaceous (9). Those lined obliquely from left to right (10, 11), Tertiary. A is London; B, Liverpool; C, Manchester; D, Newcastle.

limestones above called *Oölyte* (7 *b*), part of which is a

coral-reef limestone, showing that there were coral-reefs in the British seas of the era; and near and at the top of the series, fresh-water or soil beds, called the Portland dirt-bed, and the Wealden (No. 8). The oölyte is so named from the occurrence of beds of limestone which are made of minute spherical concretionary grains, of the size of the roe of a small fish, the word coming from the Greek for *egg*.

As the Jurassic ended there were large areas of dry land and marshes in Southeastern England. But with the commencement of the Cretaceous period there was a new submergence, and green and gray sand-beds were accumulated, followed by a deeper submergence and the formation of about 1,200 feet

Figs. 184-187.



Rhizopods.

Fig. 184, Lituola nautiloidea; 185, Flabellina rugosa; 186, Chrysalidina gradata; 188, Cuneolina pavonia.

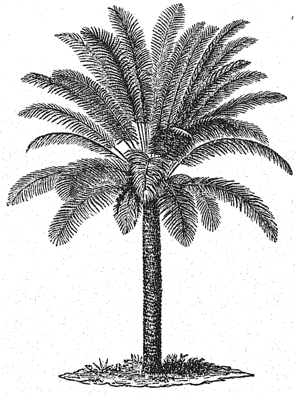
of chalk, the upper part containing flint nodules. The chalk consists very largely of the shells of Rhizopods, species not larger than fine grains of sand, some of which are here figured, much enlarged; and since, as stated on page 34, similar beds of Rhizopods are now in progress over the bottom of the Atlantic west of Ireland, and the Sponges and some other fossils of the chalk are probably deep-water species, it is be-

lieved that the chalk was formed at depths not less than 1,000 feet. The flint of the chalk was made from the siliceous Sponges, spicules of Sponges, and Diatoms of the same sea-bottom.

2. Life.

1. Plants.—The forests of Mesozoic time contained Conifers and Tree-Ferns, like the Carboniferous, but were especially

Fig. 188.

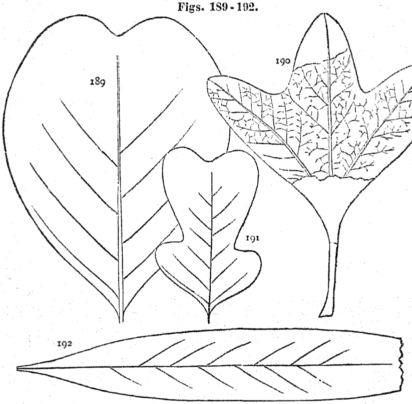


Cycas circinalis (× 1/30).

characterized by *Cycads*,—plants that looked like Palms, as the figure on page 180 shows, but were Gymnosperms, like

the Conifers. Hence the forests of the early and middle Mesozoic consisted chiefly of Tree-ferns, Conifers, and Cycads; and where the Tree-ferns and Cycads predominated the aspect was much like that of modern groves of Palms.

Figs. 189-192.



Angiosperms (or Dicotyledons).

Fig. 189, Leguminosites Marcouanus; 190, Sassafras Cretaceum; 191, Liriodendron Meekii; 192, Salix Meekii.

In the Cretaceous beds occur the first evidence of the existence, in the world, of actual *Palms* and of plants and trees now so common, related to the Elm, Maple, and other trees with net-veined leaves, — species which have the seeds in a seed-vessel, and which are therefore called *Angiosperms*, from

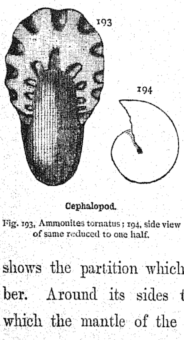
the Greek for *vessel* and *seed*. A few leaves from the Cretaceous of the United States are represented in Figs. 189 to 192.

The forests still had in some places their numerous Cycads; but their general character was changed, and for the first time they looked modern.

2. Animals. — The Corals and other Radiates had for the most part a general resemblance to those of the present era, although all were extinct and mostly of extinct genera. The same is true of the Mollusks, and yet some kinds under these classes were especially Mesozoic in type.

This is eminently true of the higher division of Mollusks, the *Cephalopods*. The chambered shells of this tribe, represented by Orthocerata, Nautili, and some related species in the Silurian, were in vast numbers under the type of *Ammonites*, while there were also many Nautili. Fig. 193 represents a front view and 194 a side view of one of the earlier of these Ammonites, — a Triassic species. The animal occupied the outer chamber of the shell, as in the Nautilus (Fig. 110, page 123). Fig. 193 shows the partition which was the bottom of this outer chamber. Around its sides there are pocket-like depressions into which the mantle of the animal descended to enable it to hold

Figs. 193, 194.

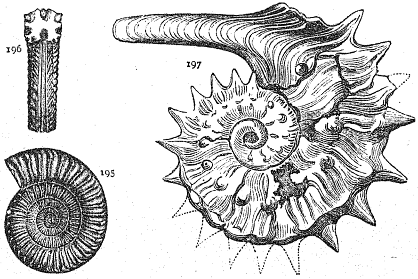


Cephalopod.

Fig. 193, Ammonites tornatus; 194, side view of same reduced to one half.

on to its shell. Two other species of Ammonites are represented in Figs. 195 – 197. Fig. 196 shows the pockets in the outer chamber of 195. Fig. 197 represents a species with the outer edge unbroken and much prolonged. The pockets are depressions in the partitions at their margins. There were some Devonian and Carboniferous species, called *Goniatites*, that

Figs. 195 - 197.



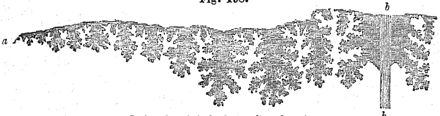
Cephalopods.

Fig. 195, Ammonites Bucklandi, from the Lias; 196, same in profile, showing outer chamber and its pockets; 197, A. Jason, from the Oölyte.

had such pockets, but the pockets were simple in outline; those of the *Ammonites* are very irregularly plicated within. Their complicated outline is well shown in Fig. 198, representing the series along half the margin of a partition in a Cretaceous species, the shaded part *a* to *b* being half of the series of pockets, twice the natural size, and *b b* the middle

line of the back of the shell. Among the Ammonites of the Cretaceous there were species four feet in diameter.

Fig. 198.



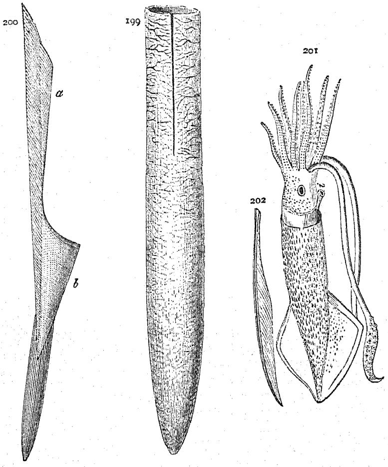
Series of pockets in Ammonites placenta.

Besides these there were other kinds of Cephalopods having *internal* shells or bones and called *Belemnites*. One of these, from the Cretaceous of New Jersey, is represented in Fig. 199, but, as usual with the fossils, it is imperfect, the upper slender part being broken off. Fig. 200 shows a side view of the bone complete, as it has been found in some species. The bone has the same relation to the animal as the pen (Fig. 202) in the modern Squid (Fig. 201), it being internal and lying in the mantle along the back; the animal of the Belemnite was much like a Squid.

These Cephalopods were in great numbers in the seas, over a thousand species having been found fossil. In view of their abundance it is a remarkable fact that no Belemnite and only one Ammonite is known to have lived after the close of the Cretaceous, and we have no evidence that by the close of the first period of the Tertiary even one was living. These highest of Mollusks thus passed their climax during the Mesozoic era.

The Vertebrates included not only Fishes and Reptiles, like the Carboniferous age, but also Birds and Mammals.

Figs. 199 - 202.



Cephalopods.

Fig. 199, Belemnitella mucronata, broken at top; 200, a Belemnite with the upper part, *a b*, perfect; 201, modern Calamary or squid, Loligo vulgaris; 202, pen or internal bone of same.

Fishes. — Ganoids and Sharks were the prevailing kinds of the Mesozoic until the Cretaceous era, and then fishes of modern type — Herring, Salmon, Perch, and the like — were in

great numbers, — species that have *bony* and *not cartilaginous* skeletons, and which are therefore called *Teliosts,* meaning *bony throughout.* They include the common edible species.

The Ganoids lost their tails, that is, the vertebrated character of the tail-fin, in the first period of the Mesozoic. Some species had then a vertebrated tail, some half-vertebrated, and others non-vertebrated, that is, had merely a caudal fin; but after the Triassic, all were of the modern non-vertebrated type.

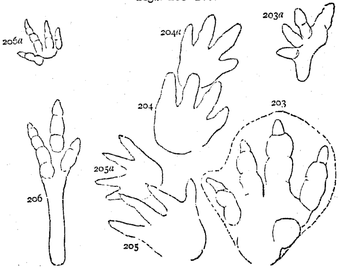
Reptiles. — Reptiles were the dominant species of the era through all the periods.

In the Triassic, the Amphibians were of great size, as shown by their footprints on the sandstones of the Connecticut valley and at some other localities, and also by the bones that have occasionally been found. Some of the largest of them walked as bipeds on feet that made tracks 16 to 20 inches long and nearly as broad, and with a stride of three feet, indicating a height of at least 10 or 12 feet. Fig. 203 shows the form of the impressions. The tracks of the much smaller forefeet are occasionally found, showing that this huge biped Amphibian sometimes brought them to the ground; the form is shown in Fig. 203 *a.* Twenty-two consecutive tracks of one of these bipeds were laid open in 1874 at one of the quarries of Portland, Connecticut. Other species have smaller tracks, and some are less than half an inch long.

Other Amphibians of the era walked on all fours. Figs. 204, 204 *a* represent the tracks of a hind foot and fore foot

of one kind, and 205, 205 *a* those of another, both from the Connecticut valley.

Figs. 203 - 206.



Tracks of Amphibians and True Reptiles.

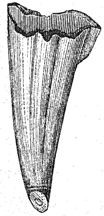
Amphibians: Figs. 203, 203 *a*, Otozoum Moodii (× 1/18); 204, 204 *a*, Anisopus Dewyanus (× 1/4); 205, 205 *a*, A. gracilis (× 2/3). — **True Reptile:** Fig. 206, 206 *a*, Anomœpus scampus, a Dinosaur (× 1/6).

All the Amphibians, there is reason to believe, had large teeth and scale-covered bodies, like the Amphibians of the Carboniferous age. A tooth of a related four-footed species from Europe is shown two thirds the natural size in Fig. 207. The head of the Amphibian that was thus armed was over 2 feet long, and three fourths as broad.

There were also true Reptiles of various kinds. One division of them, called *Dinosaurs* (meaning *terrible lizards*), had the hinder feet *three-toed like those of birds*. The tracks of one from the Connecticut valley sandstone is shown one-sixth the natural size in Fig. 206. They walked usually on their hind

legs, like bipeds, but sometimes put their forefeet down. These were four-toed. The print of the forefoot of this species is represented in Fig. 206 *a*.

Fig. 207.



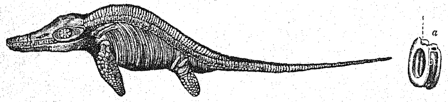
Tooth of Mastodon-saurus.

There are many kinds of three-toed tracks in the Connecticut valley sandstone which have never been found associated with tracks of the forefeet; and as they have precisely the form of those of birds, they have been regarded bird-tracks. But they may have been all made by these bird-like Reptiles.

Some of the Dinosaurs of the Jurassic and Cretaceous periods better deserve the name of *terrible lizards.* The *Megalosaur* was a huge carnivorous reptile 25 to 30 feet long; the *Iguanodon* and *Hadrosaurs* were vegetable eaters, fully as large.

Another division included *Enaliosaurs,* or the Sea-Saurians, which had paddles like whales, and were 12 to 50 feet long.

Fig. 208.

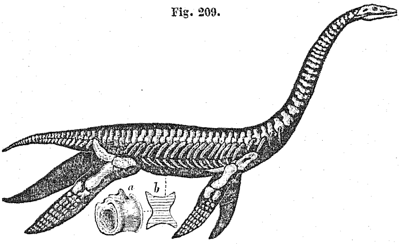


Ichthyosaurus communis (× 1/100).
a, one of the vertebræ.

One kind, called *Ichthyosaurs* (meaning *fish-lizards*) (Fig. 208), had a short neck, a very large eye, and thin vertebræ concave

on both sides (Fig 208 *a*), much resembling those of fishes. One species was 30 feet long. Another kind, called *Plesiosaurs* (meaning, *somewhat like a lizard*), had a long snake-like neck (Fig. 209), short body, and vertebræ as long as broad.

Fig. 209.

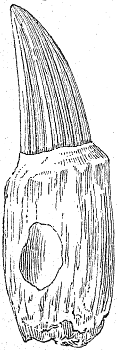


Plesiosaurus dolichodeirus (× 1/60).
a, one of the vertebræ; *b*, profile of same.

A third division included the *Mosasaurs*, — snake-like reptiles, 15 to 80 feet long, with short paddles, jaws sometimes a yard long, and the *lower jaw peculiar in having an elbow-joint* to fit it to be used like an arm for working the carcass of a great beast down its enormous throat. They had powerful teeth; one of them, about half the size of the largest, is represented in Fig. 210. Several species have been found in the Cretaceous beds of New Jersey and Kansas, along with Hadrosaurs, Dinosaurs, and other kinds.

A fourth division included Crocodiles, with long slender jaws like the Gavial, the crocodile of the Ganges.

Fig. 210.



Tooth of a Mosasaur.

A fifth division included flying Reptiles, called *Pterosaurs* (from the Greek for *winged Saurian*). One of them, reduced to one fourth the natural size, is represented in Fig. 211. The wing is made by the elongation of one of the fingers and the expansion of the skin from the side of the body. Some species from Kansas had an expanse of wing of 24 or 25 feet. They had the habits of bats.

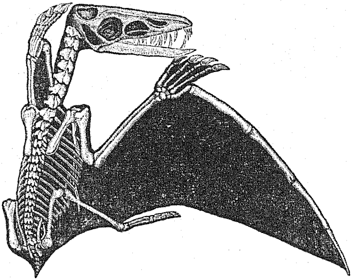
Thus the age was literally an age of Reptiles. Air, earth, and seas were all occupied by them, and by species of great magnitude, among them those of the highest grade. The Reptilian type thus had its *maximum* display in Mesozoic time.

Birds. — A bird with its feathers has been found fossil in the Oölyte of Solenhofen, Germany; and bones of a number of birds in the Cretaceous of the United States. The Solenhofen bird had a long tail, furnished with a row of long quills either side. A Kansas species, described by Professor Marsh, *had teeth set in sockets,* — a striking Reptilian character.

Mammals. — Bones from a few species of Mammals have been found, the earliest in the Triassic beds of Germany and North Carolina. Fig. 212 represents a jaw-bone from North Carolina. The remains of other related kinds have been found

in the Oölyte at Stonesfield, England, and also in the Upper Oölyte in the Purbeck beds. The species are *Marsupials,*

Fig. 211.

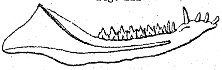


Pterosaur.

Fig. 211, Pterodactylus crassirostris (× ¼).

that is, mammals related to the Opossum and Kangaroo; they are peculiar in having a pouch (*Marsupium,* in Latin) on the under side of the body, over the breast of the mother, for

Fig. 212.



Dromatherium sylvestre.

receiving the young, which are born in an immature state. Nearly all modern Marsupials are confined to the continent of Australia; a few exist still in America.

Thus all the classes of Vertebrates had, in Mesozoic time, their species, even to Birds and Mammals. As early as the Triassic, its first period, the Amphibians passed their climax in numbers, size, and grade, little being afterward known of the huge scale-covered tribe; and during its following periods true Reptiles had their time of greatest expansion, giving a strong Reptilian character to the Reptilian age. But the Birds and Mammals which appeared in the age were only the commencement of tribes that were to reach their fullest display in later time. Both the early Birds and Mammals had marks of inferiority, and also characteristics that showed some relation to the Reptiles with which they lived. Thus the Birds had long tails, and some, at least, true teeth like Reptiles; and the Mammals have been called *semi-oviparous*, that is, kinds whose young were in an immature state when born, approximating in this respect to the egg state, which is an example of an extreme degree of immaturity. It is also a fact of interest that among Reptiles the Dinosaurs were like birds, not only in their biped mode of locomotion, but in the special way by which they were adapted to this kind of progression; for they had the same kind of feet as birds, the same number of toes, the same number of joints to the several toes, also hollow bones in part, a somewhat similar structure in the hinder part of the skeleton to which the leg-bones are articulated, and other points of resemblance.

The progress in the life of the world in Mesozoic time is

also seen in the fact, that with the opening of its third period, Sharks and Ganoids were no longer the only fishes, the modern tribes having made their appearance; and, too, Conifers, Tree-ferns, and Cycads were not the only forest-trees, for already Palms and Angiosperms had added vastly to the variety of foliage and to the richness of the flowers and fruits. Of lines of transition from the older trees up to these Palms and Angiosperms nothing is known.

The old law of change characterized the life of Mesozoic time. New fossils are found in every successive rock-stratum, and also older kinds are missed. The system of life was in course of expansion by the introduction of new species and a casting off of the old.

3. Mountain-making in Mesozoic Time.

The Sierra Nevada, Wahsatch, and some other ranges of the western slope of the Rocky Mountains were made at the close of the Jurassic. All the strata there existing from the bottom of the Silurian to the top of the Jurassic were folded up in the making of the Wahsatch Mountains, and probably in that of the Sierra Nevada.

In the course of the Jurassic, or at its close, the Triassic (or Triassic and Jurassic) rocks of the Atlantic border (Connecticut River valley and elsewhere) were slowly tilted; and then occurred a great number of deep fractures, mostly parallel in course to the direction of the areas of the sandstone,

which opened down to a region of liquid rock; for the liquid rock came to the surface and cooled, and now constitutes many ridges, such as Mount Holyoke, Mount Tom, the Palisades on the Hudson, and others between Nova Scotia on the north and South Carolina. During the formation of the sandstone a slow sinking was in progress, as is proved by the footprints on the surfaces of layers and other markings, these showing that the layers — originally mud-flats and sand-flats of an estuary — were *successively* at the water-level. The sinking brought a strain on the rock-made bottom of the trough, and ended in a breaking of the crust, and thence came the ejections of trap. The trap resembles the cooled rock of most volcanoes, but is commonly much more compact.

IV. — Cenozoic Time.

Cenozoic Time comprises two Ages: —

I. The Tertiary, or Age of Mammals.

II. The Quaternary, or Age of Man.

I. The Tertiary, or Age of Mammals.

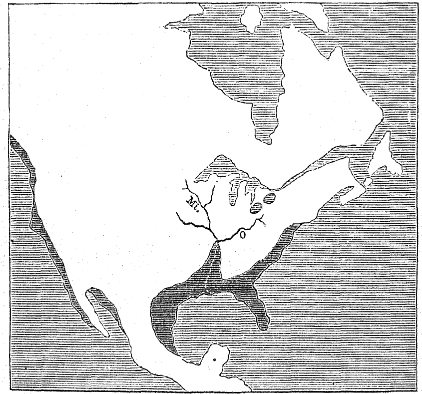
The Tertiary age has been divided into three sections: (1) the Eocene; (2) the Miocene; (3) the Pliocene. These terms signify, severally, (1) the *dawn of recent time;* (2) the *less recent;* (3) the *more recent.* The areas of Tertiary rocks in North America and England are distinguished on the maps,

pages 105 and 114, by being lined from the left above to to the right below.

1. Rocks.

In the accompanying map the white area represents the dry land of the continent in the Eocene, or early part of the

Fig. 213.



Map of North America in the early part of the Tertiary Period.

Tertiary. Only the borders of the Atlantic, the Gulf of Mexico, and the Pacific (the shaded portions) were covered by the sea, and over these parts Tertiary rocks were forming through marine action aided by the contributions of rivers.

The geographical changes since the opening of the Cretaceous period were great, as will be seen by comparing the map with that on page 177. The Rocky Mountain region was now above the sea. The rivers of the eastern part of the continent, or those contributing waters and sediment to the Atlantic, had two thirds or more of their present extent; but the Ohio and Mississippi were still independent streams, emptying together into an arm of the Mexican Gulf. The Missouri and other western streams were just beginning to be. The Mountain region but slowly emerged, and till near the close of the Tertiary there were great lakes instead of great rivers. In the Eocene the lakes occupied the Green River and other summit basins. Afterward they were farther east and west, and in the Pliocene, as Marsh states, a lake extended from Northern Nebraska to Texas. The Tertiary consequently includes, from its beginning, vast *fresh-water* as well as *marine* formations.

Marine Tertiary beds of the Eocene period were formed on the Atlantic border south of New York, and on the borders of the Mexican Gulf; but Miocene only on the Atlantic border, some change of level having excluded them from the Gulf border west of Florida; and Pliocene along the coast region of South Carolina, though of this there is doubt. On the Pacific border there are marine beds, both of the Eocene and Miocene periods; the latter are most extensive.

Underneath the Marine Eocene beds of the Lower Mississippi

there are *Lignitic* beds, that is, beds containing lignite — a kind of mineral coal retaining usually something of the structure of the original wood — alternating with beds that are partly marine, the whole indicating that fresh-water marshes there alternated with fresh-water lakes and salt seas; for the Lignitic beds were once beds of vegetable débris such as are formed in marshes.

Fresh-water Tertiary beds cover large areas over the Rocky Mountain summit region, and its eastern slope, as well as part of its western in Oregon and elsewhere. They were formed in and about the great lakes alluded to above. Immense numbers of bones of mammals and many entire skeletons are contained in these beds, showing that the shores of these lakes were the resort of wild beasts, some of them of elephantine size. In the Green River basin and other parts of the summit region the beds are Eocene; while over the eastern slope they are mostly Miocene and Pliocene, the latter of widest extent.

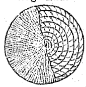
Underneath these fresh-water beds over the eastern slope in the region of the Upper Missouri, and far north in British America, as well as far south, there is a Lignitic formation which is partly, especially below, of brackish-water origin; and these are equivalents of the Lignitic beds below the marine Eocene of Mississippi. Over the summit region of the mountains the Lignitic formation has a thickness of several thousand feet, and instead of Lignitic beds there are val-

uable beds of mineral coal. There are marine, brackish-water, and fresh-water strata in the formation, the latter mainly in the upper part. The coal-beds occur in Wyoming, Utah, and Colorado, and some of them, opened near the Pacific Railroad, afford coal for its locomotives. These beds overlie the Cretaceous beds conformably, and the latter also have similar coal-beds; so that the Cretaceous deposits and era here blend with the Tertiary. Moreover, a very few Cretaceous shells occur in some of the marine beds and the remains of some reptiles related to the Cretaceous Dinosaurs. The great majority of the fossils are Tertiary in aspect and genera, and they are therefore here referred to the Eocene, although regarded as Cretaceous by some geologists. These Lignitic beds and the underlying Cretaceous were all upturned together in one mountain-making effort, before the fresh-water Eocene beds of the Green River basin were deposited.

In Great Britain there are marine Eocene Tertiary beds in the "London basin," and next a thin Pliocene stratum, no marine Miocene existing there. Over Europe and Asia the Eocene formation was widely distributed, showing that those continents, even as late as the early Tertiary, were largely under the sea. The Pyrenees, portions of the Alps, Apennines, Carpathians, and mountains in Asia were partly made of them. The beds in many places contain the coin-shaped foraminifers (Rhizopod shells) called *Nummulites*, varying from half an inch to one inch or more in diameter; and the limestone of

which some of the Egyptian pyramids are built is made up chiefly of Nummulites. One of them is shown in Fig. 214; the exterior is represented as removed from part of the interior to show the cells, which were once occupied by the minute Rhizopods. Some species of a related genus occur in modern coral seas. They must have been exceedingly abundant over the great continental seas of the Tertiary. Miocene beds have a thickness of several thousand feet in Switzerland (constituting the Rigi and some other summits), and occur in many other parts of Europe; but they are limited in area compared with the Eocene. Marine Pliocene beds are of still less extent, yet have a thickness in Sicily of 3,000 feet.

Fig. 214.



Nummulites.

The marine Tertiary rocks are very various in kind. The larger part are soft sand-beds, clay-beds, and shell deposits, the shells often looking nearly as fresh as those of a modern beach. Others are moderately firm sandstone. There are also loose and firm limestones. The green sand called "marl," used as a fertilizer, which is so characteristic of the Cretaceous, also constitutes beds in the Tertiary of New Jersey.

The *fresh-water* beds are like the softer marine beds, but contain, of course, no marine shells. Part of them are quite firm; but others are easily worn by the rains. Some great areas in the Rocky Mountain region, both over the summit and the eastern slope, have been reduced in this way

to areas of isolated ridges, towers, pinnacles, and table-topped hills, that are mostly barren, owing to the dry climate, and which are therefore called "Bad Lands," or in French (in which language the expression was first applied), "Mauvaises Terres."

2. Life.

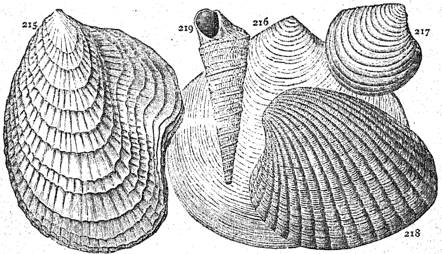
The life of the Tertiary age shows in all its tribes an approximation to that of the present time. The mammals, and probably the birds, are all of extinct species. But among the plants and the lower orders of animals there were many species that still exist: in the Eocene, a small percentage; in the Miocene, 25 to 40 per cent; and in the Pliocene, a much larger proportion. The common oyster and clam were living as far back as the Miocene era, along with a large number of shells that are now extinct species. Progress through the Tertiary era was gradual in all departments.

The forests of North America were much like the modern, but with a larger proportion of warm-climate forms. Palms flourished over Europe and in England through the Eocene. In the Miocene the European species were still those of a warmer climate than the present, and included some Australian species. Even in the Arctic zone there were in the Miocene great forests of Beach, Oak, Poplars, Walnut, and Redwood (Sequoia, the genus to which the "great trees" of California belong), with Magnolias, Alders, and others.

The modern aspect of the marine shells is shown in the

following figures: Figs. 215–219, of American Eocene species, and 220–223, of Miocene from the Atlantic border.

Figs. 215-219.

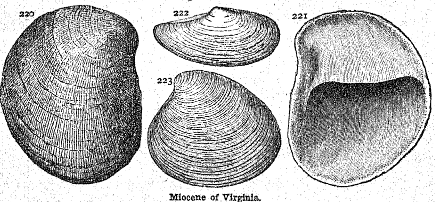


Eocene of Alabama.

Fig. 215, Ostrea sellæformis; 216, Crassatella alta; 217, Astarte Conradi; 218, Cardita planicosta; 219, Turritella carinata.

This is further manifest in the following figures of fresh-water shells from the Lignitic beds of the Rocky Mountain regions,

Figs. 220-223.

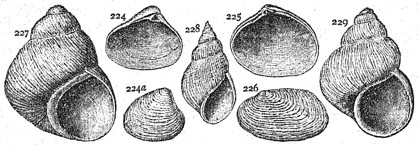


Miocene of Virginia.

Figs. 220, 221, Crepidula costata; 222, Yoldia limatula; 223, Callista Sayana.

— species which are supposed to prove that those beds are Tertiary instead of Cretaceous. To appreciate the change since

Figs. 224-229.



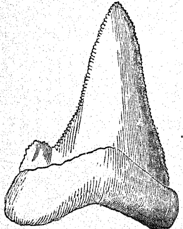
Shells of the Lignitic Beds.

Lamellibranchs: Figs. 224, 224 *a*, Corbula mactriformis; 225, Cyrene intermedia; 226, Unio priscus. — **Gasteropods:** Fig. 227, Viviparus retusus; 228, Melania Nebrascensis; 229, Viviparus Leai.

Paleozoic time, the reader should turn back to the figures of shells on pages 121 to 133.

The Tertiary *Vertebrates* were more unlike the moderns than the Invertebrates. Among fishes, Sharks were exceedingly abundant, and their teeth, the most enduring part of the skeleton, are very common in some of the beds; and those of one kind, pointed, triangular in form, were nearly as large as a man's hand. One of the smaller of these teeth is represented in Fig. 230.

Fig. 230.



Shark's tooth.
Carcharodon angustidens.

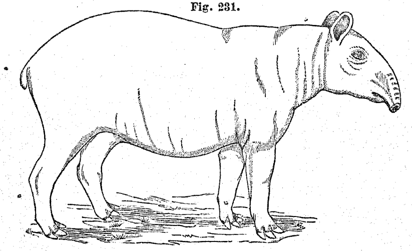
The true Reptiles were Crocodiles, Lizards, Snakes, gigantic and smaller Turtles, and others.

Among the birds there were Owls, Woodpeckers, Cormorants, Eagles; and those of France included Parrots, Trogons, Flamingoes, Cranes, Pelicans, Ibises, and other kinds related to those of warm climates.

The Mammals of Mesozoic time, thus far discovered, were probably all of the lower order called *Marsupials;* but with the opening of the Cenozoic era there were true Mammals. The Eocene beds about Paris, France, afforded to Cuvier the first specimens described; and now they are known from all parts of the world, and from none in greater variety than from the fresh-water Tertiary region west of the Mississippi.

The earliest kinds were related most nearly to the mod-

Fig. 231.



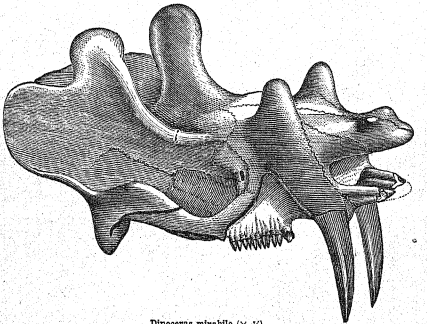
Tapirus Indicus, the modern Tapir of India.

ern Tapir (Fig. 231), Hog, Rhinoceros, and Hippopotamus. There were also kinds between these and the Deer. All the above mentioned are *Herbivores*, that is, *plant-eaters*. There

were also *Carnivores,* or *flesh-eaters,* related to the dog and wolf, and Monkeys related to the Lemurs.

One of the Herbivores of the Rocky Mountain Eocene is the *Dinoceras* of Marsh, — a figure of the skull of which is here given. It was nearly as large as an Elephant, but had

Fig. 232.

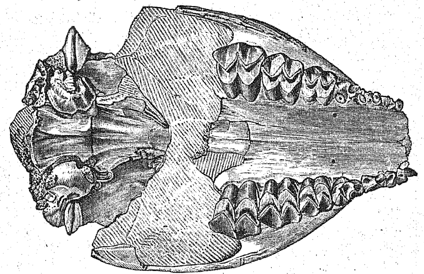


Dinoceras mirabile (× ⅛).

six horns and was somewhat related to the Rhinoceros. Fig. 233 represents the skull of one of the Miocene species, — an *Oreodon,* — which was intermediate in characters between the Deer, Camel, and Hog. The form of a European species more like a Deer, called a *Xiphodon,* is given, as restored by Cuvier, in Fig. 234. There were also Horses through the Tertiary; but while the modern Horse has only

one toe out of the full mammalian number *five*, some of the Pliocene had three toes, one large, and two too short for use;

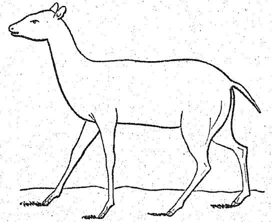
Fig. 233.



Oreodon gracilis.

Miocene kinds had three toes, and all usable; and the Eocene had four toes, and all usable.

Fig. 234.



Xiphodon gracile.

In the Miocene and Pliocene there were Mastodons, Elephants, Rhinoceroses, Camels, and Monkeys over the Rocky Mountain region, besides many smaller species. The marine Tertiary of the Atlantic border has afforded, as should be expected, but few of these species. Cattle related to the Ox have not been found in beds earlier than the Pliocene.

The Mammalian type was at last extensively unfolded, its grand divisions being well represented. But the maximum display of the brute races took place *still later*, in the early or middle Quaternary, after Man had appeared.

3. Mountain-making.

In North America, after the deposition of the coal (or Lignitic) beds of the summit region of the Rocky Mountains, and of similar beds in California, there was a flexing and upturning of the strata along with those of the Cretaceous beneath, — which together, as has been stated, make one continuous series, — and ridges over 3,000 feet and more high were thus made in the coast region of California, and others of greater height in Mexico, New Mexico, Colorado, and to the north.

During the formation of the Lignitic beds the uplifting of the whole Rocky Mountain region above the sea was in progress; for such beds of vegetable débris as they were made from show that long periods of rest above the sea alternated with shorter periods of submergence. After the epoch of up-

turning which followed, if not also contemporaneously with it, this elevation was continued, and without a return again below the sea-level. But the existence of the vast fresh-water lakes over the surface proves, as first observed by Hayden, that the rising went forward with extreme slowness, and probably with long delays at intervals; and it is quite certain that the present height — at least 10,000 feet in Colorado and Wyoming above the level in Cretaceous times, since the Cretaceous beds, full of marine fossils, are now at this height — was not attained before the close of the Pliocene, if it was then.

The Pyrenees, Apennines, part of the Northern Alps, and other high mountains of Switzerland, the Carpathians, and other mountains in Eastern Europe were raised thousands of feet, and the mountain regions in Western Thibet, in Asia, 16,500 feet, after the Eocene Tertiary had partly passed, and the rise perhaps began at the same time with that of the Cretaceous and Lignitic mountains of the Rocky Mountain summit and the coast region of California.

After the Miocene another range 2,000 to 3,000 feet in height was made along the California coast-region west of the Cretaceous range, and some disturbances took place in the Tertiary over the summit region of the Rocky Mountains.

The close of the Miocene was a time of great disturbance and of mountain-making also in Europe, to the north of the Alps, in Switzerland, and elsewhere.

At the same time, that is, in the Miocene era, great eruptions of igneous rocks took place over the western slope of the Rocky Mountains, covering thousands of square miles; and probably the deep fractures were then opened which gave origin to the volcanoes Mount Shasta, Mount Hood, and other summits in the Cascade Range. So also along the coast of Ireland and of Scotland, and the Inner Hebrides to the Faroe Islands, the eruptions were of great extent. Fingal's Cave and the Giant's Causeway date from this period.

In each case over the Rocky Mountains the making of a mountain range was preceded, as in that of the Appalachian region (page 168), by a sinking of the earth's crust where the range was to be, and the accumulation in the trough, as it formed, of some thousands of feet of deposits. Then followed the catastrophe, — as explained for the Appalachian region on page 172, — causing upturnings, foldings, fractures, consolidation; and sometimes also a crystallization of the beds, changing them to granite, gneiss, and allied rocks. Each time, after a mountain system was completed, that part of the earth's crust was too much stiffened to be the site of another sinking trough, and consequently the trough made later, if there was any so made, was to one side of the former. In the Tertiary the crust over the whole Rocky Mountain region had finally become so stiffened that no new trough was begun after the Miocene; and instead of a folding of the thick Miocene formation into a mountain range, great breaks of the

crust took place from which floods of lavas were let loose and the lofty volcanoes were begun.

4. Climate.

During Mesozoic time the Arctic zone was warm enough for great Reptiles,—warm-climate species,—and the British seas for coral-reefs.

The close of the Cretaceous was probably an era of unusual cold, sending cold oceanic currents from the Arctic zone; for no other cause will account for the general destruction of species that then took place over the continental seas of America, Europe, and Asia. But the Eocene era was one of warm climate again over Great Britain,—for England was then a land of Palms; and Palms continued to flourish over Middle and Southern Europe during the Miocene period. Through both the Eocene and Miocene the Arctic lands were covered with forests, and hence the Arctic climate must have been comparatively warm,—not colder at least than the present climate of the Middle United States and Northern Prussia. There was a cooling off with the progress of the Miocene, and by the close of the Tertiary the earth had probably its frigid, temperate, and torrid zones, nearly as now.

2. Quaternary Age, or Era of Man.

The scene of work for the Quaternary age was to a large extent widely different from that of the Tertiary and preceding

ages; and the kind of work was equally different. With the close of the Tertiary the continent, which was begun in the nucleal V of Archæan time, was finished out very nearly to its present limits, and at its close an elevation added the Tertiary formation of the sea-border to the dry land.

This accomplished, the Quaternary opened. Agencies were now at work over the broad surface of the continent — its dry land, and not continental seas, as formerly — transporting southward gravel and earth from regions to the north, in order to cover the hills with gravel and soil and fill the valleys with alluvial plains. Over both Europe and America transportation went forward from the high latitudes southward, except where there were mountains sufficiently lofty to be sources of independent movements. Hills and valleys were no impediment to the great agent engaged in this immense continental system of transportation. The aid of the ocean was not needed in these movements, and was not given except to a small extent along its borders.

After these great results were attained the work of the rivers went on more quietly, and finally, through this and other agencies, in connection with some change of continental level, the earth assumed slowly its present perfected condition of surface and climate.

The age is divided into three periods: — (1) the GLACIAL period; (2) the CHAMPLAIN period; (3) the RECENT or TERRACE period.

1. Glacial Period.

1. Glacial Phenomena. — The general facts are these:—

In America and Europe, over the northern latitudes, sand, gravel, stones, and masses of rock hundreds of tons in weight are found from a few miles to a hundred and more south of the region whence they were derived. This transported material is called *drift*, and the stones or rocks, *bowlders*.

In North America, the region over which the transportation took place embraced the whole surface from Labrador or Newfoundland to the western borders of Iowa, and farther west for a distance not yet determined, and it reached southward to the parallel of 40° and in some places beyond this. In Europe it included the British Islands and Northern Europe, down to the parallel of 50°, where the temperature is about the same as along the parallel of 40° in North America. The direction of travel was generally to the southeastward, southward, or southwestward.

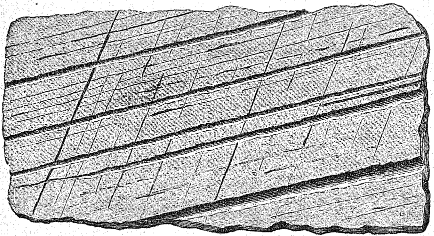
The fact and the direction of transportation have been ascertained by tracing the stones to the ledges from which they were derived. Thus bowlders of trap and red sandstone from the Connecticut valley are found on Long Island, and masses of granite, gneiss, quartzyte, and other rocks in New England, to the southward or southeastward of the ledges that afforded them. In the same manner masses of granular marble have been proved to have come from a formation 50 or

100 miles to the northward of their present position. So again masses of native copper are found in Indiana and Illinois that were brought from the veins of native copper south of Lake Superior. The greatest distance to which bowlders have been traced has been 400 or 500 miles in Europe, 200 or 300 over Eastern North America, and 1,000 miles along the Mississippi River valley, where they reach nearly to the Gulf.

The masses sometimes contain 2,000 to 3,000 cubic feet, so that they compare well in size with large houses.

Drift regions are also regions of extensive planings, polishings, and scratchings of the rocks (Fig. 235). These

Fig. 235.



Drift scratches and planings.

scratches may almost anywhere be found on rocks that have been recently uncovered. Vast areas are thus scoured and scratched over, and the scratches have great uniformity in direction. The bowlders also are scratched.

Scratches and bowlders occur on top of Mount Mansfield, the highest point in the Green Mountains, 4,430 feet above the sea, and at a level of 5,500 feet on the White Mountains in New Hampshire; and the direction of the scratches shows that the transporting agent moved over both of these summits without finding in them any serious impediment, and thence continued on its way southeastward.

The drift covers the mountains and hills of drift regions, and makes also a large part of the formations in the valleys. Over the hills it is *unstratified drift*, the sands, gravel, and stones having gone down pell-mell together; in the valleys it is *stratified drift*, — stratified because there the sands and gravel were deposited in flowing water, which sorted somewhat the material and spread it out in beds. The excavations in cities or villages for the cellars of houses are often made in the stratified drift, and the sands usually show a succession of beds which is evidence of the action of water.

2. Cause of the Glacial Phenomena. — No known agent is adequate for transportation on so vast a scale excepting *moving ice*. And, as Agassiz was the first to appreciate, it was *glacier* ice. The size of the blocks transported is no greater than is now borne along on the backs of glaciers; and the planing and scratching is just what the Alps everywhere exemplifies. The moraines of the glaciers, as explained on page 60, are derived in the Alps from the cliffs either side of the ice-stream, and a small part only are taken up by the abrad-

ing surface at bottom. In the Continental glacier of the Glacial period, the stones, gravel, and sand were gathered from the hills *over which* the ice moved, for there were no cliffs or peaks projecting above the surface even in hilly New England. The White Mountains, as above stated, have scratches to a height of 5,500 feet, or to within 800 feet of the summit, and therefore were buried in the great glacier nearly to its top, and in snow, if not ice, for the rest. Taking the height at the White Mountains as a guide, the upper surface of the glacier at that point was at least 6,000 feet above the sea-level, and the thickness of the mass about 5,000 feet. From this region it sloped away over Southern and Southeastern New England to its place of discharge in the Atlantic. A thickness of even 2,000 feet, which is over four times that of the largest Alpine glacier, would have given great abrading power to the heavy mass. All soft or decomposed rocks would have been deeply worn away by it, and hard rocks with open joints or planes of fracture torn to pieces; and the heavily pressing, slowly moving mass would have taken the loose and loosened rock-material over the hills beneath into itself, as additional freight for transportation.

Masses of trap 500 to 1,000 tons in weight lie along the elevated western border of the plain of New Haven in Connecticut, which were gathered up from the trap hills between Meriden and Mount Tom in Massachusetts. The hills are 1,000 to 1,300 feet high, and their tops, when the masses

were taken up, were 1,500 to 2,000 feet below the upper surface of the overlying glacier.

A glacier moves in the direction of *the slope of its upper surface,* in spite of the slope of the surface beneath it. It is like thick pitch in this respect. If pitch were dropped indefinitely over a spot *in a plain,* it would spread away indefinitely; and if the surface around had a rising slope, it would fill up the basin and then keep on its course. So it is with the ice of a glacier. In order to have a southeastward course, a glacier must have its surface highest to the northwestward with slope southeastward; and if the snows were more abundant to the north in the Glacial era, and the melting less abundant there, than to the south, an accumulation to the north might have gone on that would have produced movement southward. If the plain beneath the pitch had deep channels obliquely crossing it, the pitch *in these channels* would follow their direction, while the overlying pitch kept on its main course. So with the glacier: its lower part within the large valleys followed the directions of the valleys, as the scratches and bowlders show; while the upper portion had its usual course, — the course which is indicated by the scratches elsewhere over the higher parts of the country.

The cold of the era may have been mainly due to an elevation and extension of Arctic lands, increasing the area of Arctic land-ice; and to a partial closing, through this eleva-

tion, of the Arctic region against the warm current of the Atlantic Ocean, the Gulf Stream, which is now a source of warmth to all of Northeastern Europe, and even Iceland, Nova Zembla, and the polar seas and lands. Other reasons for cold have been suggested, references to which will be found in large works on the subject.

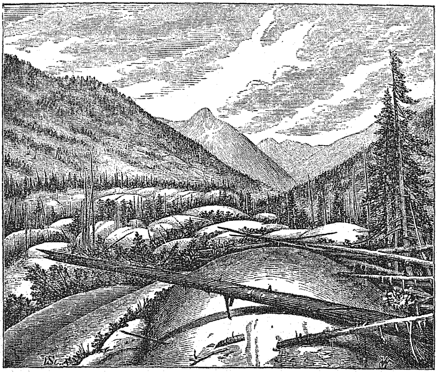
South America has its Glacial region, and evidences of transportation toward the equator; so that the phenomena described were not confined to only one hemisphere. Some writers suppose it to have been alternately in the two hemispheres. But the evidence of this does not appear to be satisfactory.

The moving glacier of New England appears to have had its head in the height of land between the St. Lawrence valley and Hudson Bay; for the scratches diverge from this region over Eastern Maine, New Hampshire, Vermont, and New York, being in Western New York and the region just east of Lake Huron southwest in direction.

South of drift latitudes there were glaciers of great magnitude about the higher mountains; and moraines, scratches, *roches moutonnées*, occur on a grand scale in many valleys of the higher ridges of the Rocky Mountains and the Sierra Nevada, as mementos of their former Glacial history. The accompanying sketch (Fig. 236) of *roches moutonnées* in one of the higher valleys of Colorado is repeated here from page 61, because the events indicated belong to the Glacial period.

The *roches moutonnées* extend along the valley through an ascent of nearly 2,000 feet. At present there are no glaciers within 500 miles of the place.

Fig 236.



View on Roche-Moutonnée Creek, Colorado.

In the same era a glacier in the Alps buried all Switzerland 2,000 to 4,000 feet deep in ice, and left immense blocks of Alpine rocks on the Jura Mountains.

Depositions of earth and stones from the glacier must have been going on to some extent through the whole Glacial era. The perpetual grinding of stones against stones in a glacier makes a very fine clayey earth; and a clay of this kind was dropped

over the hills and in the valleys, making thick deposits; and as these deposits often contain large bowlders, derived likewise from the glacier, they are called *bowlder-clays*.

2. Champlain Period.

1. Melting of the Glacier and Deposition of the Drift. — The larger part of the deposition of the drift was delayed until the glacier melted. There is reason to believe that during the Glacial period the land over the northern latitudes stood at a higher level than now, and that this was one cause of the occurrence of a cold era. Whether this were so or not, the glacier was made finally to disappear through a sinking of the land over northern latitudes, which brought on a milder climate and determined, and then hastened, the melting. This subsidence marks off the commencement of the *Champlain period*, the second period of the Quaternary. The earlier part of it was the era of the melting of the great glacier. The melting would have gone on for a long time with extreme slowness; but when the glacier was thinned down to the last 500 to 1,000 feet, in which part of it the most of the gravel and stones were, it went forward rapidly; and then took place the pell-mell dumping of gravel and stones over the hills and valleys, with the stratification of whatever fell into the waters. At last, as the facts prove, there was an immense flood owing to the rapidity of the final melting; for the later depositions in many regions are greatly coarser than

the earlier, the finer material having been swept away down stream and into the ocean.

The Mississippi valley was the outlet for the waters of the great region it now drains; and the flood during the whole Glacial period must have been great, and floating ice laden with northern stones must have often hurried off down stream to the Gulf. But at the final flood it made thick deposits on the way to the Gulf, as observed by Hilgard, and in Mississippi bowlders as large as a bushel basket are found in the beds.

Icebergs thus despatched to the Mexican Gulf must have made havoc of the warm-water life; and it is therefore no occasion for surprise, as Hilgard remarks, that the sea-shore drift deposits contain no marine species of shells.

The subsidence, with which the Champlain period opened, was greatest to the north, being over 500 feet on the St. Lawrence near Montreal, 400 feet on Lake Champlain, over 200 feet on the shores of Maine, and but 40 to 100 feet along Southern New England. The river-beds hence did not have even their present slope, and consequently the rivers in part became great lakes. For the same reason the flood waters made deposits of great breadth along the river valleys and lake regions,—the greatest fresh-water deposits of geological history. The depth of the submergence at Montreal, on Lake Champlain, along the coast of Maine, and most other points on the sea-coast is proved by the occurrence of sea-shore depos-

its full of sea-shells at the heights just stated. In the beds on Lake Champlain the bones of a whale have been exhumed, which lived in the waters of the lake in the Champlain period, when it was a great arm of the enlarged St. Lawrence Gulf. All the rivers and lakes over the continent in the latitudes north of 40°, and partly those south of it, have high alluvial plains at a level far above the river or lake they border; and they were made in this Champlain period when the land was below its present level.

2. Champlain Period after the melting. — After the melting was completed, the rivers, though still at flood height, were more quiet in their action, and they made depositions in the river-valleys, wherever these were not already filled to the flood level, of a finer alluvium; and much of this alluvium contains fresh-water shells, and occasional bones of quadrupeds. The amount of sand, gravel, and clay which had been dropped over the hills by the ice was immense, and it lay loose, easy to be taken up by streams the rains might make; and hence the filling of the valleys even after the ice had disappeared may have gone forward for a while with much rapidity. But the finer alluvium shows that before the Champlain period ended the flow of the larger streams was comparatively quiet.

In Europe and Great Britain the Champlain period was one of subsidence over the higher latitudes, as in America, and the subsidence was greatest to the north. In France and

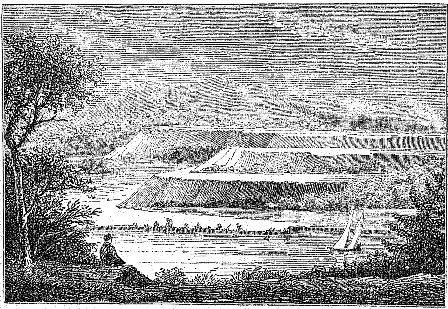
Belgium the depression below the present level was 50 to 100 feet; in Southern England, 100 to 200 feet; in Northern England and Scotland, as reported by British geologists, 1,000 to 1,400 feet. In Sweden it was 200 at the south to 400 or 500 to the northeast,—so great that an ocean channel then connected the Baltic with the White Sea. The alluvial deposits on the Rhine, below Basle, are in some places 800 feet or more in height above the river. But this height does not indicate a depression of as great an amount in the Champlain period; for much of it was owing to the piling of the flooded waters in the narrow valley. The distance from Basle in a straight line to the North Sea at the mouth of the Rhine is about 400 miles; and if the flood from the melting glacier increased the slope of the surface of the waters on an average only 2 feet a mile, the flood level at Basle would have been 800 feet above the present level of the river.

3. Recent Period.

The Champlain period was brought to a close by a raising of the land over the higher latitudes, bringing the continent finally up to its present level. This elevation placed the old sea-beaches of the Champlain period high above the sea, at their present level, that is, over 500 feet near Montreal, over 200 feet on the coast of Maine, and so on, as above stated; and this level is approximately a measure of the elevation. River-valleys, after the rise, had a much steeper slope than in

the Champlain period, and hence their flow was increased in rate. They consequently went on cutting down their beds through the Champlain deposits of the valley to a lower level; and at the time of their annual floods they wore away the deposits on either side of the channel, making thereby an alluvial flat or flood-ground, — for every river has a flood-ground which it covers in its times of flood, as well as a channel for dry times. This sinking of the river-beds left the old flood-grounds as a high terrace far above the level of

Fig. 237.

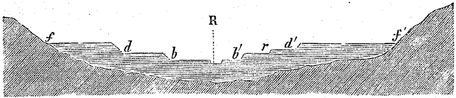


Terraces on the Connecticut River, south of Hanover, N. H.

the stream; and the great elevated plains still remain to attest to the vastness of the floods from the melting glacier. In the course of the elevation a series of terraces was often

made along the valleys, as illustrated in the accompanying view (Fig. 237). A section of a valley thus terraced is represented in Fig. 238. The formation terraced is, as is shown, the Champlain; and in the Champlain period it filled in general the valley across (from *f* to *f'*), excepting a narrow channel for the stream, the whole breadth having been the

Fig. 238.



Section of a valley with its terraces completed.

flood-ground of the Champlain River. But after the elevation of the land that closed the Champlain period began, the river commenced to cut down through the formation, making one or more terraces in it, on either side of the stream. In Fig. 238, R is the position of the river-channel after the terracing; and on either side of it there are terraces at the levels *f f'*, *d d'*, *b b'*, and also another on the right side at *r*. These terrace-plains are usually the sites of villages. They add greatly to the beauty of the scenery along all water-courses. The terraces fail where the valley is narrow and rocky.

Between the Champlain and Recent periods, or in the opening part of the latter, Europe passed through a second, but less severe Glacial epoch. Marks of it have been pointed out in glacial deposits in the Alps and other places, but espe-

cially through the occurrence in great quantities of remains of the Reindeer, a high-latitude animal, in Southern France. With the bones of the Reindeer there are also those of other cold-climate species. This epoch is called the *Reindeer* era; and the part of the Recent period following it the *Modern* era.

4. Life of the Quaternary.

1. General Observations. — The plants and the lower tribes of the Animal kingdom in the early part of the Quaternary were essentially the same as now. The species of corals making coral-reefs in the tropics were probably in existence and at work before the close of the Tertiary age; and the same is true of part of the Insects, Fishes, Reptiles, Birds, and Mammals of the modern world, perhaps of a large part.

There must have been some exterminations as a consequence of the cold of the Glacial period, and of the ice of high latitude regions. Many plants were driven south by the coming on of the cold, and thus escaped destruction; and some of these now live on Mount Washington and other high summits of temperate North America. Birds must have shortened their northward migrations and lengthened them southward, and for the most part may have escaped catastrophe. The beasts of prey, cattle, and other large mammals of Drift latitudes must also to a great extent have moved toward the tropics as the rigors of the approaching ice-period began to

be felt. Certain it is, that after the ice had gone there was a large population of brute Mammals over Europe and the other continents; and facts seem to prove that they hung about the southern limit of the ice, and often moved northward with the lulls in the intensity of the climate or the shortening-in at intervals of the ice-field.

2. Brute Mammals. — The brute mammals reached their maximum in numbers and size during the warm Champlain period, and many species lived then which have since become extinct. Those of Europe and Britain were largely warm-climate species, such as now are confined to warm temperate and tropical regions; and only in a warm period like the Champlain could they have there thrived and attained their gigantic size. The great abundance of the remains and their condition show that the climate and food were all the animals could have desired. They were masters of their own wanderings and had their choice of the best.

The relics have been found in deposits along the margins of rivers and lakes; in marshes, where they were mired; in caves, buried in the stalagmite (page 24) that had been deposited over them. In Britain and Europe the caves were the haunts of Bears, Hyenas, and Lions, much larger than any of the kind now living; these beasts of prey dragged into them the bodies of the animals they fed upon. The Cave-Bear resembled much the Grizzly Bear of Western North America; and the Cave-Hyena and Cave-Lion are re-

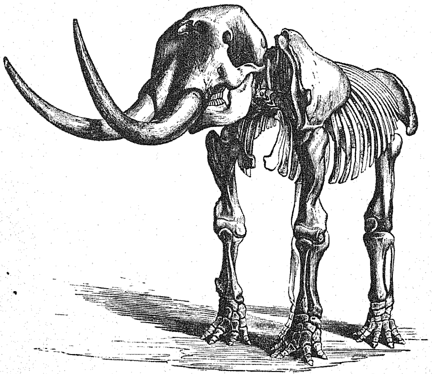
garded as the same in species with the African Hyena and Lion, although these modern kinds are dwarfs in comparison.

With these there were in Britain and Europe species of Rhinoceros, a Hippopotamus, the Siberian Elephant or Mammoth, the Brown Bear, Wolf, Wildcat, Lynx, Leopard, Fox, Elk, Deer, and others. The modern Horse was among them, yet gigantic in size like many of the other Mammals of that genial period. The Irish Deer (*Cervus megaceros*), skeletons of which have been found in Irish bogs, had a height to the tip of the antlers of 10 to 11 feet, and the span of the antlers was sometimes 12 feet. The Elephant (*Elephas primigenius*) and the most common Rhinoceros (*R. tichorinus*) had a hairy covering, and this fitted them to wander off into regions far north; their remains, especially those of the Elephant, show that they lived in great herds over Northern Siberia, where now the mean temperature of the year is 5° to 10° F. The Rhinoceros had a length of 11½ feet, and the Elephant was nearly a third taller than the largest of modern Elephants.

In North America also there were large Lions and Bears, but none of them, as far as known, made caves their dens. The largest of the species was the *Mastodon* (Fig. 239), an animal with tusks and trunk like an Elephant. When full grown it was 12 to 13 feet in height, and to the extremities of the tusks 25 feet long. The teeth had a crown as large in area as this page, and of the form shown in Fig. 240. Skeletons have been found in marshes where the heavy beasts were

mired; and portions of their undigested food — the small branches of spruces and other trees — have been taken from between their ribs, where the stomach once was.

Fig. 239.



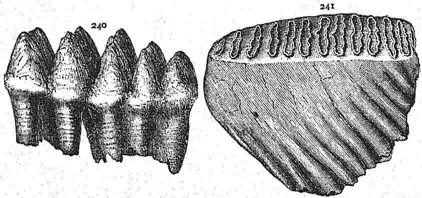
Skeleton of Mastodon Americanus.

There were also American Elephants of great size, much resembling the Siberian. Fig. 241 represents a tooth of one of them found in Ohio; it is a little larger than that of the Mastodon. There were also Horses of large size, Tapirs, Oxen, Beavers, and various gigantic species of the tribe of Sloths.

The Sloth tribe was especially characteristic of South America. The modern Sloth is as large as a Dog of medium

size. These species of the Champlain period included a *Megatherium* (Fig. 242), which was larger than the largest of

Figs. 240, 241.

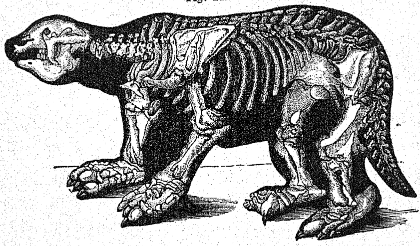


Teeth of Mastodon and Elephant.

Fig. 240, Mastodon Americanus (× ¼); 241, Elephas Americanus (× ¼).

existing Rhinoceroses. As the figure shows, it was a lazy beast,—the bones of the hind legs being much like logs, and

Fig. 242.

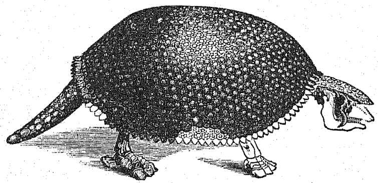


Megatherium Cuvieri (× 1/75).

those of the fore-feet furnished with hands a yard long for

pulling down trees after raising itself erect on its hind legs and enormous tail — a third support — for the purpose. This is one of many kinds of gigantic Sloth-like animals that lived in South America during the era. Other related species had a shell somewhat like the modern Armadillo; and these also were gigantic, one of them (Fig. 243) measuring 5 feet across its shell, and having a length of at least 9 feet.

Fig. 243.



Glyptodon clavipes (× 1/30).

In Australia the Mammals are now, with some small exceptions, *Marsupials,* the Kangaroo being one of them. They were also Marsupials then; but the ancient kinds partook of the peculiar feature of the era, — great magnitude, some of the species being as large as a Hippopotamus, one having a skull a yard long, and many of them being far larger than any modern Marsupial.

Thus the brute races of the Middle Quaternary on all the continents exceeded the moderns greatly in magnitude. Why, no one has explained.

The genial climate of the Champlain period was *abruptly* terminated. For carcasses of the Siberian Elephants were frozen so suddenly and so completely at the change, that the flesh has remained untainted. Near the close of the last century, one huge carcass dropped out of the ice-cliff at the mouth of the Lena, and for a while made food for dogs. The existence of a hairy covering was then first ascertained. A hairy Rhinoceros has also been found in the ice. This change of climate was probably connected with the commencing of the Reindeer or second Glacial era; and it was then that the Reindeer and some other species succeeded in migrating to Southern France, there to live until the cold epoch had passed. The remains of the Reindeer are found along with those of the Cave-Bear, Cave-Hyena, Rhinoceros, Elephant, and other Champlain species, showing that all lived together there at that time.

3. Man. — Man was in existence during the Champlain period; and probably in its earlier part before the ice had disappeared (a part often included in the Glacial era by geologists).

Relics, indicating that he was a contemporary of the gigantic Champlain Mammals, occur in various caverns and in river and lacustrine deposits, in Britain, Europe, Syria, and in other regions.

The relics of Man are stone implements, such as arrowheads, hatchets, pestles, and stone chips made in the manufac-

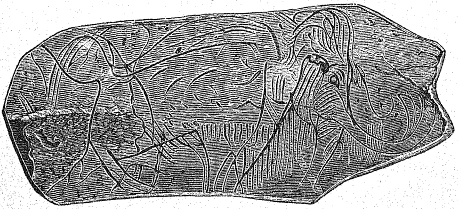
ture of the implements; bones, shells, and other materials having upon them his markings or carvings; his pottery; the charcoal left from his fires; the bones of animals broken lengthwise to get out the marrow; his own bones, skulls and skeletons.

In Europe and Western Asia the stone implements of the earlier part of what is sometimes called the *Stone age* are of rude make and unpolished. This part of the age has been called the *Paleolithic* era in human history, or that of the *oldest* stone implements, — the word, from the Greek, signifying *old* and *stone.* The stone implements occur along with bones of the Cave-Bear, Cave-Hyena, Mammoth, Rhinoceros, and several other Champlain species, and also with the bones of Man; and these human relics are so associated with those of extinct Mammals that there is no reason to doubt that they were contemporaries.

Next came the Reindeer era. Its stone-implements are unpolished, but better made than those of the preceding era. Besides these there are examples of bones, shells, horn and stone engraved with the forms of animals, and others that are variously carved, or made into spear-heads and other forms, and also perfect human skeletons. Fig. 244 represents a drawing, on ivory, of the hairy Elephant; it was found in the cave of La Madelaine, in Perigord, Southern France, and shows that the Elephant was well known to the men of the period. These human relics are associated with remains of

the same Champlain Mammals that occur in the earlier deposits, and also with great numbers of the bones of the Reindeer, and many of the Aurochs, Elk, Deer, and other species of later time.

Fig. 244.



Elephas primigenius; engraved on ivory (× ⅔).

Next followed an era in which the implements were still of stone, but often polished, and in which the remains of the Reindeer are rarely found, and those of the peculiar Champlain species not at all, but instead portions of skeletons of the domestic dog and other existing quadrupeds, with much broken pottery. This era in the Stone age is called the *Neolithic*, from the Greek for *new* and *stone*. The shell-heaps (Kitchenmiddens) of the Danish Isles in the Baltic are among the Neolithic localities.

The bones and skeletons of Man of this Stone age in no case indicate a race inferior to the lowest of existing races, or intermediate between Man and the Man-Apes, — the species among the brutes which approach him most nearly. But still

they are those of uncivilized Man, and in part of Man of a low order of faculties.

The skeleton of Neanderthal (a part of the valley of the Düssel, near Düsseldorf) is the worst, but it is not older than others having better skulls and higher foreheads. The capacity of the cranium was 75 cubic inches, which is greater than in some existing men. A jaw-bone of low type, found in the oldest Belgian deposits, had little height and great thickness, as if for powerful use, and the posterior of the molar teeth was the largest, — a brutal feature.

The skeletons of the Reindeer era in Southern France are in part those of men of unusual height, — 5 feet 9 inches to over 6 feet; and the skulls are large and well shaped, with the foreheads high and capacious. They are of better size and shape than many of the Reindeer era in Belgium, which are small and after the Laplander type.

One of the most perfect was found in the stalagmite that formed the floor of the cave of Mentone, near the borders of France and Italy, on the Mediterranean. Eight feet above it in the stalagmite there were remains of the extinct Rhinoceros and other Champlain species. The man would compare well, if we may judge from the skeleton, with the best among civilized races, — his forehead broad and high, and rising with a facial angle of 85°, his height 6 feet; and yet he was a European savage of the Reindeer, if not Paleolithic era; for about him lay his flint implements and weapons, his chaplet

of stag's canines, and shells that he had gathered for food or ornament from the shores near by. The tibia or shin-bone was somewhat flattened, a peculiarity often observed in the skeleton of the American Indian. The brain-cavity of a skull found in the cave of Cro-Magnon, in Southern France, had a capacity of 97 cubic inches, which is very much above that of ordinary Man, and nearly three times that of the highest Man-Ape.

In North America cases of the occurrence of ancient human bones or skeletons in Quaternary deposits are not as well authenticated as those in Europe. Admitting the facts that have been published, they do not give Man greater antiquity than those above mentioned.

No case of the presence of human relics in deposits of the Tertiary age on any continent is yet well established. Mr. W. Boyd Dawkins, an excellent British geologist and original observer in this department of the science, states, in his recent work on Cave-Hunting (1874), that the evidence obtained proves that "Man lived in Germany and Britain after the maximum Glacial cold had passed away," and that no human remains "have been discovered up to the present time in any part of Europe which can be referred to a higher antiquity than the Pleistocene (Quaternary) age." The human relics thus far found in Syria and Asia lead to no greater antiquity for Man. Migration into Europe along with the Champlain Mammals in pre-Glacial time is suspected; but on this point there are as yet no known facts.

The second Glacial epoch in Europe and Asia (which there is reason to believe produced effects also in North America) appears to have finally brought to a close the era of giant beasts, leaving the world for Man.

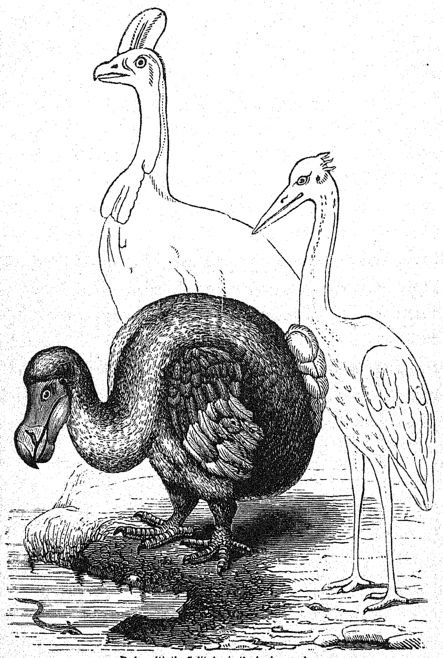
The Age of Man still continues; and now it has as its fossils, not only flint implements and human bones, but also buried cities, temples, statues, manuscripts.

The system of life, long in progress, finally reached its completion in a being that could search into the earth's history, study Nature's laws, investigate the system of the universe, judge of right and wrong in himself and others and will the right; and who has thus the highest credentials of kinship with the Infinite Author of physical and moral law. The progress of chief interest hence is no longer the development of animal races and characters, but the exaltation of Man in the direction of his higher nature.

5. Geological Work still going Forward.

Rock-making has not yet ceased; for the old agencies — the waters, the winds, and life — are still at work with unimpaired energies. Sand-beds, pebble-beds, and mud-beds are accumulating along sea-shores and in shallow waters, precisely like those that were hardened into ancient sandstones, conglomerates, and shales; and limestones are forming from shells and corals similar to ancient limestones. Moreover, modern

Fig. 245.



Dodo, with the Solitaire in the background.

From a painting, at Vienna, made by Roland Savery, in 1628.

fossils include, besides human remains, corals, shells, and relics of all the various tribes of the era, as in past time.

Further, species are becoming extinct; at least through Man, if not in other ways. The Dodo, an extinct chicken-like bird of 50 pounds weight (Fig. 245), was living on Mauritius in the 17th century. The Moa, larger than an Ostrich, and other birds with it, have recently disappeared from New Zealand. The Aurochs (*Bison priscus*) of Europe is nearly extinct. Thus wild animals have begun to disappear before advancing Man. The same is true of plants.

Again, changes of level are still going on. A large part of Sweden is rising at the slow rate of 4 feet or so a century, and as slowly a portion of Greenland is subsiding. Such movements, along with earthquakes, prove that contraction from the cooling of the earth's crust has not ceased.

Hence, although the earth is in its finished state, enough of geological work is now going on to enable Man to decipher the records of the past.

V. — Observations on Geological History.

1. Length of Geological Time.

To the question, What is the length of geological time, geology gives no definite reply. It establishes only the general proposition that *time is long*.

The Cañon of the Colorado (page 78) is a gorge 200 miles long, bounded the most of the way by steep walls of rock over 3,000 feet in height, cut through sandstones, limestones, and other rocks, and at bottom over parts of it, for several hundred feet, into granite; and above the lofty walls a few miles back from the stream the pile of nearly horizontal strata is continued in mountains to a height of 7,000 to 8,500 feet above the bed of the river. All the facts, as its describers testify, point to running water as the agent that made the great channel. The region was under the sea until the close of the Cretaceous period, for marine Cretaceous strata are the uppermost rocks. It follows, then, that all this extensive excavation was accomplished by slow-acting water during Cenozoic time. Surely Cenozoic time was very long.

The gorge of the Niagara River below the Falls has a length of 7 miles. It is the work of the waters since the middle of the Champlain period; for in the first place, a former channel leading from the Whirlpool toward Lake Ontario was entirely filled by the gravel and sands thrown in by the melting glacier during the earlier part of that period; and, secondly, Champlain beds containing shells of Lake Erie and a tooth of the Mastodon, formerly spread over the place where the gorge now is, as shown by the remains of the formation above on the Canada side. The water has consequently made this vast excavation, 7 miles long, since Man

appeared. The rate of progress of the Falls up stream is not satisfactorily ascertained; the most rapid rate that has been estimated would give more than 30,000 years for the work.

The thickness of a sedimentary deposit is no satisfactory basis for determining the length of time it took to form. In a sea 100 feet deep 100 feet of sediment may accumulate; and the thickness could not exceed this (except a little through wave-action and the winds) if a million of years were given to it.

Let the same region be undergoing a subsidence of an inch a century, and the thickness might increase at that rate; and much faster if a yard a century; and with either rate, giving time enough, any thickness might be attained. Hence a stratum of sandstone 100 feet thick may have been formed in a thousandth part of the time of a thin intervening bed of shale.

Nevertheless, the aggregate maximum thickness which the strata attained during the several ages may be used for an approximate estimate of the comparative lengths of those ages. On such data, it is deduced that the time-ratio for Paleozoic, Mesozoic, and Cenozoic time was not far from 12 : 3 : 1. Consequently, if we suppose the length of time since the Paleozoic began to be 16 millions of years, Paleozoic time will include 12 millions, Mesozoic 3 millions, and Cenozoic 1 million. Most geologists would make the whole interval several times 16 millions.

2. Progress in Features.

The earth through the ages made progress, —

1. In its surface features: from the condition of a melted sphere as featureless as a germ, to that of an almost universal ocean with small lands, — enough of land to mark out the feature-lines of the future continents; and at last — after slow expansion southward, a lifting of mountain ranges at long intervals, and a retreating of the waters — to the existence of great continents having high mountain borders and well-watered interior plains.

2. In its river-systems: from the existence of only little streamlets draining small lands in the Archæan and Silurian eras, and making no permanent geological record beyond a rain-drop impression; to a condition of vast fresh-water lakes and marshes when beds of vegetable material accumulated for the making of coal-beds; and finally to that of the completed continent, when a single river with its tributaries drains, waters, and contributes fertility to hundreds of thousands of square miles of surface, and the work of fresh waters in rock-making exceeds that of the ocean.

3. In its climate: from a condition of general uniformity of temperature, to, at last, — though with interrupted progress, — that of the present diversity, when the poles have a permanent capping of ice, and only the equatorial regions perpetual verdure.

4. **And, again, in its living adornments:** from an era when the small rocky lands were bare, or gray and drear with lichens, and all other life was of the simplest kind and below the water-level; to a time of flowerless forests and jungles over immense plains, yet with no sounds from living Nature more musical than the Amphibian's croak; and onward to the better time when the earth abounds in flowers and fruits and birds, and is covered with the homes of Man.

3. The System of Nature of the Earth had a beginning and will have an end.

A system of progress or development in the earth as much implies that it had a beginning, as that in any plant or animal. Man, Mammals, Fishes, Mollusks, Rhizopods, Plants, all had, according to geological history, their beginning; so also mountains, valleys, rivers, continents, rocks. And so also the earth; and therefore the system of nature, whose development went forward in and through it, had its beginning.

If this is true of one sphere in space, we may rightly take another step and assert that *the universe had its beginning.*

It also admits of demonstration that the earth will have its end. A finished state is always the state before decline and death. The earth is dependent for all the beauty in its living adornments, and even for the existence of its life, on the heat and light of the sun. The sun is losing annually its

heat; and however infinitesimal the amount of loss, it is sure to end in a cooled and dark sun; and hence, even long before the sun is cold, the earth, supposing it to have met with no earlier catastrophe, will have become dark and lifeless,—literally a dead earth.

4. Progress in Life.

1. The progress in life was in general from the simpler forms to the more complex, or from the low to the high.— This truth has been illustrated in each chapter of the preceding geological history.

2. The progress was by gradual steps.—Species appeared and disappeared, not only at the beginning of ages, or of the subdivisions of ages called periods, but also during the progress of periods, each of the successive strata containing some fossils not found below, and failing of others that are abundant in underlying beds. There were at times epochs of wide-spread catastrophe, ending periods, and two of them, those closing Paleozoic and Cenozoic time, were nearly or quite universal for the continental seas. But these must have left unharmed the life of the deep ocean; and they may not have exterminated all the life of the emerged land, or even of the whole area of continental seas.

3. The progress was according to system.—The first animal life was probably the Protozoan,—or Rhizopods, Sponges, and the like; kinds that are minute and destitute of members.

But later the four great systems of structure — the Radiate, Mollusk, Articulate, and Vertebrate — were defined; and the species which appeared afterward in the long succession were constructed according to one or the other of these systems. Each system, by the new species that came into existence as time moved on, became displayed in higher and more diversified forms. The first of the Vertebrates were the Fishes, — the simplest of its tribes. Even in these limbless species the arms and legs of the higher Vertebrates were present, though only in the state of fins; and the lung, though only as a cellular air-bladder; and the ear, though only as a closed cavity containing a loose bone; and so with other parts. Thus the earliest of Vertebrates possessed in an incipient stage many of the organs that became fully developed in the later and higher Vertebrates. And in the succession of species that existed, all were made on the fish-structure as its basis, even the species of the highest class, — those of Mammals and Man. A zoölogist, in order to understand the fundamental elements in the human structure, goes to the fish and the frog for instruction; and Nature is so true to her fundamental principles, that he there finds what he looks for.

4. The system of progress is rightly called a system of development or evolution. — With every step there was an unfolding of a plan, and not merely an adaptation to external conditions. There was a working forward according to preestablished methods and lines up to the final species, Man,

and according to an order so perfect and so harmonious in its parts, that the progress is rightly pronounced a development or evolution. Creation by a divine method, that is, by the creative acts of a Being of infinite wisdom, whether through one fiat or many, could be no other than perfect in system, and exact in its relations to all external conditions, — no other, indeed, than the very system of evolution that geological history makes known.

5. The system not one of regular progress upward, but one involving the culmination and decline of some tribes as the general unfolding went forward. — As has been brought out in the history, the division of Trilobites, Brachiopods, and Crinoids, besides others, reached their maximum, or culminated, in Paleozoic time; of Amphibians, in the first period of the Mesozoic era; of Reptiles and Ganoids among Vertebrates, and of Cephalopods, the highest of Mollusks, in the later Mesozoic; of brute Mammals, in the Champlain period of Cenozoic time. So, again, in the kingdom of plants, the highest Cryptogams — the Acrogens — culminated in the Carboniferous period, that is, the later Paleozoic; Cycads, in the middle Mesozoic; while Palms and Angiosperms have the present era as their time of greatest display and perfection. These are a few examples, showing that progress did not go on regularly upward; but that the old, not only in species, but also in tribes and orders, were culminating and then passing away, as new and higher tribes were introduced, in the progressing evolution of the kingdoms of life.

6. Parallelism between the progress of the system of life and the progress of individual life. — An animal, in its growth from the germ, — or, as it is called, its embryonic development, — passes through a succession of forms before reaching the adult state. In Mammals the changes after birth are small, the larger part of them having taken place before birth. But in the lower animals the successive forms are often widely diverse, and they frequently mark successive stages in the life of the animal. Thus, in Insects, there is the caterpillar or grub stage, before the adult; and in many Crustaceans, Mollusks, Worms, and Radiates there are several such stages.

Now species have existed — and many now exist — which have the general characters of the forms in these lower stages; and, in accordance with the above proposition, the order of their appearance in the geological series is, in general, as announced by Agassiz, that of their development in the embryonic series. Thus, as the worm-like grub precedes the adult insect, so Worms, in geological history, preceded Insects. As a fish-like condition of an Amphibian precedes the adult form in which the fish-like feature is lost, so Fishes preceded Amphibians. The examples of the principle are numerous. Some authors have so great faith in it, that they are ready to decide as to the form of the earliest species of a tribe from the earlier stages in individual development. But this is unsafe, since such forms may have come late into the system of life as well as early; inasmuch as progress was not in all cases upward progress.

Where the parallelism above mentioned is not apparent in the general form or structure, it is still manifested in certain comprehensive laws common to both kinds of progress, the geological and embryonic. The following are some of these laws.

a. The low before the relatively high.

b. The simple before the complex. A germ has little distinction of parts; the animal it is to evolve is there in a very general condition, that is, without any special organs. As development of a Mammal goes on, the defining of the head begins, and this is one of the first steps in the evolving of special parts, or in the specialization of the structure. Protuberances also form and commence the defining of the limbs; and then, finally, the parts of the limb become distinct, or are specialized. Thus it is throughout the structure, until the specialization of the parts peculiar to the particular animal is completed.

This law of *the general before the special* is a law also in the geological progress of the system of life. In a fish, the earliest of Vertebrates, the vertebrate structure is exhibited in its most generalized condition. The vertebral column consists of one single uniform range of vertebræ without a neck portion, and without a pelvis to divide the body from a tail and afford support to hind limbs; the limbs are fins, and hence only rudiments of limbs; the vertebræ have great simplicity of form; the teeth are all of the simplest kind; the lung is merely an air-bladder, and so on. Thus, all through the structure, a fish

is an exhibition of the vertebrate type in a generalized state. The Vertebrates which succeeded to fishes, the Amphibians, have the grand divisions of the body well brought out, and are specialized also as to limbs even to the toes, and in other ways. Passing onward in time, the new Vertebrates appearing exhibited successively a more and more complete specialization of organs and functions, up to Man. In the development of Man from the embryo, it is not true that he passes through a fish-like condition; but it is the case that certain fish-like characteristics may be observed in the structure, during its earlier progress; and one of these is an opening beneath the jaws, which Dr. Wyman has regarded as representative of the gill-openings of Fishes.

This law of progress by specialization has its exceptions; for Snakes, which are limbless, succeeded to higher reptiles which had limbs. But such cases only exemplify another fact, already illustrated, — that, while upward progress was the rule, there was also progress downward, and especially after the time of culmination of a tribe had passed.

c. *Stationary forms sometimes before the locomotive.* Thus, (1.) Crinoids, part of the earliest life of the globe, were *stationary* species living attached by a stem; and, after these, there were *free* Asterioids. So the young of the modern Crinoid has a stem for attachment, and loses it, in many species, as it becomes an adult (a Comatulid). (2.) The earliest Brachiopods were attached species, and so are the young of all existing Brachiopods.

d. Forms in a group having the body elongated posteriorly, and endowed behind with locomotive power, generally precede those that are shorter behind and superior in the anterior portion of the body and head, — a headward transfer of the forces of the structure marking all upward progress. The young of a crab has an elongated locomotive tail-extremity, which it loses as it develops to a crab; and so the long-tailed shrimps preceded crabs in geological history. The young of a modern Ganoid or gar-pike has an elongated vertebrated tail, which it loses with the change to the adult; and so Ganoids in Palæozoic time had vertebrated tails, but in Mesozoic time lost them. In the young of some birds the tail segments of the vertebral column are much elongated and free, but, with progressing development, they become greatly contracted, and often consolidated together; and so the earliest Birds, in part, at least, had long vertebrated tails. The young of an Insect is an elongated, worm-like grub; and so Worms preceded Insects. The embryo of Man in an early stage of development has a tail half as long as that of a dog in the same stage.

The principle is a general one through the animal kingdom. This shortening behind is directly connected with, or a consequence of, a transfer forward of the forces of the animal structure by which improvement is given to the anterior extremity, and a higher grade of power and functions to the head. Progress from the embryo in animals is always attended with a gradual improvement of the head extremity, and

also with changes of form in adaptation to it; and, parallel with this, progress in the system of animal life, from its earliest beginnings onward, was similarly attended, under all tribes, by a headward transfer of power in the being, and by such structural changes as this involved. Marsh has shown that the Carnivores and Herbivores of the early Tertiary had brains but a half or a third as large in bulk as those nearest related to them in type and size among modern species.

This kind of progress is progress in *cephalization;* this term being derived from the Greek for head. And the principle here illustrated may be briefly announced as follows: *Progress both in the system of animal life and in individual life is eminently progress in cephalization.*

Man, the last and highest being in the system of life, derives his exalted position from the extreme degree of cephalization which characterizes his structure. Besides having a great brain and great head power, his fore-limbs are removed from the locomotive series, and turned over to the service of the head, and, as is involved in this transfer, his body is erect. Thus, by an abrupt transition, he stands apart from the ape and all brute races.

7. The transitions between species, in the system of progress, not yet proved to be gradual. — The systematic succession in the progress of life, made manifest by facts derived from the rocks, leads many to hold that the whole has been as much a growth under the control of physical law as is proved to be

true of the development of the earth's features. Geological history has accordingly been appealed to for evidence as to whether species, instead of being independent types of structure, are so linked together by gradual transitions, that we cannot reasonably avoid the conclusion of their production from one another by gradual change. That evidence it has not yet afforded. This is admitted by all, even by those who believe that the transitions were gradual. Geology has brought to light fewer examples of gradual transition than occur among living species. The wide intervals that have separated related groups are diminished from time to time by the discovery of remains of intermediate species. It has been thus for the interval between the Elephant and Mastodon, and for that between the Horse of modern time and the Tapir-like animals of the early Tertiary (page 204); and the same in many other cases. And yet the new species found have still strong specific differences, and those that have thus far been discovered between the Horse and Tapir are of distinct genera; so that the idea of *abruptness between species* is not yet set aside by geological evidence.

But geological evidence on this point is, as has been often urged, far from satisfactory. The record is unquestionably very imperfect. The following are examples.

It is certain that there were birds in the Jurassic period in Europe, for one with its feathers has been found fossil. But thus far we know of but that one specimen out of the many; for if there was one there were myriads.

There is the same evidence that there were Marsupial Mammals during the Triassic era in North America, and therefore during the Jurassic and Cretaceous eras following; and yet only two jaw-bones of Triassic Marsupials have been found in all the American Mesozoic rocks.

There was abundant life in the oceans of the long Triassic and Jurassic eras; but, nevertheless, not a fragment of any species has been found in the Triassic or Jurassic rocks on the Atlantic border of North America; and the Triassic of the Rocky Mountain region is as destitute of marine life. The American record respecting marine species of the Atlantic border for the long time between the Carboniferous and Cretaceous eras is utterly a blank.

Again, of the plants of the great forests that covered the American continent in the Triassic and Jurassic eras less than 50 species are known; and yet the whole of the dry land of the continent must have been covered, and the kinds through all that time must have been very numerous.

These are examples of the imperfection in the record, and they naturally weaken much the force of geological evidence. But if they weaken it, they do not authorize the conclusion that the transitions were always gradual.

There are some gaps of great width. Of the species connecting Mollusks or other Invertebrates with the first of Fishes, geology has afforded not a fact: it has found only great Sharks, Ganoids, and Placoderms as the earliest spe-

cies. With regard to the Palms, which first appeared in the Cretaceous, none of the preceding links have been found; and none for the Elm, Magnolia, and various other Angiosperms that accompanied the first Palms. Bones of true Mammals are very abundant in the Tertiary strata; and yet in the Cretaceous beds, those next earlier, there are numerous remains of great Reptiles, and not a trace, as yet observed, of the true Mammals.

8. Origin of Man.—The interval between the Monkey and Man is one of the greatest. The capacity of the brain in the lowest of men is 68 cubic inches, while that in the highest Man-Ape is but 34. Man is erect in posture, and has this erectness marked in the form and position of all his bones, while the Man-Ape has his inclined posture forced on him by every bone of his skeleton. The highest of Man-Apes, the Orang-utan, cannot walk without holding on by his fore-limbs; and, instead of having a double curvature in his back like Man, which well-balanced erectness requires, he has but one. The connecting links between Man and any Man-Ape of past geological time have not been found, although earnestly looked for. No specimen of the Stone age that has yet been discovered is inferior, as already remarked, to the lowest of existing men; and none is intermediate in essential characters between Man and the Man-Ape. Until the long interval is bridged over by the discovery of intermediate species, it is certainly unsafe to declare that such a line of intermediate species ever existed, and as unphilosophical as it is unsafe.

If, then, the present teaching of geology as to the origin of species is for the most part indecisive, it still strongly confirms the belief that Man is not of Nature's making. Independently of such evidence, Man's high reason, his unsatisfied aspirations, his free will, all afford the fullest assurance that he owes his existence to the special act of the Infinite Being whose image he bears.

9. Man the highest species. — It is sometimes queried whether the future may not have its various new species of life, and, among them, some higher than existing Man; whether the age now passing is not to be followed, as was true of the Carboniferous, or the Reptilian, by another still more glorious in its living species; whether, if one of the great Dinosaurs of the Mesozoic age could have thought about his own and other times, he would not have imagined his age the last and the best possible, and whether Man is not playing as foolish a part in styling himself the "lord of creation."

Against the introduction of new species in coming time science has little to urge. But there is strong reason for holding that, whatever the changes in the lower tribes, existing Man will always remain the highest in the series.

(1.) Science has made known that the highest of species next to Man, that is, the brute Mammals, have already passed their maximum (page 225); hence, the rest of time remains for the culmination of the only higher type, that of Man. And, as this type includes now but one species, we have reason for expecting no new species in the future.

(2.) From geological history we learn also that the type of Vertebrates commenced in kinds that were *horizontal* in attitude, — the Fishes; and that from the horizontal there was, in the Reptiles and Mammals, a raising of the head above the line of the body, up to the Ape, in which the attitude is nearly vertical; and, finally, to perfect verticality in Man, a being having the head placed directly over the body and hind limbs. Thus, as Agassiz observed, the last term in the series has been reached; there can be nothing beyond. This is true as to the general type of structure; but it leaves it an open question whether there may not be other species of Man, or erect beings, of still higher grade.

(3.) But a different species of Man higher than existing Man is not a possibility. We can conceive of other species of Man distinguished by having some of the external features of the Man-Apes. But these are marks of inferiority, and, if possible in a type of so high grade, could belong only to inferior species.

The increasing erectness and breadth of forehead in Man, and the shortening of the jaws, giving a nearly vertical line to the front, which are a known result of culture, indicate the course which *upward* progress must take. And in these points and some others closely related, the limits of perfection have been nearly reached by some among the present race. Further improvement can give physically only larger capacity to the brain and greater beauty of form to the

whole structure, and make these qualities more general. No wide divergence from existing Man can be conceived of. When all possible change in these directions has been accomplished, Man will still be Man, and no more the head of the system of life than he is at present.

(4.) Beyond all this we may say, that since no Dinosaur, and no other species but Man, has ever been capable of reviewing the past or contemplating the future; and since Man not only has all time and all Nature within the range of his thought and study, but can even yoke Nature for service, and in fact has her already at work for him in numberless ways,—the system with such a head must be complete.

Nature, through Man, has attained to the possession of a living soul capable of putting her once wasted energies into strong and combined movement for social, intellectual, and moral purposes, and this is the consummation that the past has ever had in prospect.

The Man of the future is Man triumphant over dying Nature, exulting in the freedom and privileges of spiritual life.

INDEX.

NOTE.—The pronunciation of some of the scientific words is indicated by an accent.

THE END.

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